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Glenayre
electronics

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AUTOMATIC RAIL CAR IDENTIFICATION

Prepared for the

Transportation Development Centre
of Transport Canada

by

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17. Abstract

This report describes a continuation of the development of RAILOCATOR, an electronic system for automatic railcar identification.

Railocator comprises a passive transponder affixed to the underside of a railcar, an interrogator antenna placed on the crossties between the rail, and a controller that receives, recovers, checks and stores/forwards the railcar identification numbers. The interrogator antenna serves to energize the transponder by means of a low frequency magnetic field and to provide a high frequency field, which is the medium for data transmission. When energized, the transponder continuously modulates the high frequency field with its identification number.

The system has been extensively tested in the laboratory, under conditions which realistically simulate field operating conditions. A rotating-arm test rig gives speeds of up to 200 km/h, and high levels of environmental noise were injected into the data. After more than 20 million readings were taken under a variety of operating conditions, a missed reading rate of approximately 1 in one million readings was recorded and no errors were observed.

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17. Résumé

Ce rapport rend compte de la poursuite des travaux de mise au point du système électronique RAILOCATOR conçu pour le repérage automatique des wagons.

Ce système se compose de transpondeurs passifs montés sous les wagons, d'une antenne d'interrogation placée sur les traverses de la voie ferrée entre les rails et d'un contrôleur qui capte, vérifie, stocke ou transmet les numéros d'identification des wagons détectés. L'interrogateur a pour fonction d'exciter le transpondeur au moyen d'un champ magnétique basse fréquence et d'émettre en même temps un champ porteur haute fréquence qui servira à la transmission des données. Excité, le transpondeur module en continu ce champ HF selon un mode propre à son numéro d'identification.

Ce système a fait l'objet d'essais poussés en laboratoire, simulant les conditions réelles de fonctionnement. Un montage rotatif simulant une vitesse maximum de 200 km/h a été utilisé tout en créant une ambiance acoustique représentative des niveaux rencontrés en service. Après plus de 20 millions de passages réalisés dans des conditions variables, le taux d'erreur est resté nul et on a dénombré un seul cas de détection ratée par million de passages.

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1. INTRODUCTION

North American and other railroads have long had an interest in automatically recording the identification of rolling stock entering and leaving terminal areas. Systems which have been implemented include optical "bar-code" labels, closed-circuit TV and a variety of electronic devices. As experience has been accumulated on a number of railroads it appears that electronic labels which hold promise of very high performance in their ability to transfer information without error are becoming of primary interest.

1.1 Background

In 1968 North American railroads adopted an optical labelling system called Kar-Trak, for railcar identification. This system was plagued with technical difficulties, poor reliability, and high cost through and in 1978 was officially abandoned by the Association of American Railroads (AAR) as an industry standard supported by all member railroads. Use of ACI was quickly abandoned by almost all railroads at great cost in wasted investment, and the subject of automatic railcar identification was not popular with most senior railroad officials. In 1978 the AAR issued a generic specification for what might be required as a replacement for ACI and then completely abandoned the topic. Some railroads have used closed-circuit TV to read numbers, most others have relied on advanced train consist information transmitted between computers to advise of arriving car numbers.

In recent years many railroad operators have conceded that presently available systems for railway car identification have major drawbacks, and that a label system, if highly reliable, would make a major improvement in the efficiency and effectiveness of handling material.

Glenayre Electronics Ltd.has been involved in the development of identification label technology for railway applications since 1972. The original design, now known as DIGITRAC, has been applied primarily to the location of trains and locomotives by placing the label on the railway roadbed and the reading equipment in the locomotive.

In considering the use of DIGITRAC for electronic labelling of railway rolling stock, some major shortcomings in that technology became apparent:

1. Data content was insufficient
2. Physical size was too great
3. Cost was intrinsically high and could not be reduced

With the prospect of major business opportunities, particularly with South African Railways, a project was undertaken with financial assistance from the NRC IRAP program to develop a label technology more suitable to railcar identification.

The operating principle of Railocator, using "field effect" for the transmission of binary data, was demonstrated in the Glenayre laboratory in 1978. An Engineering Development Model (EDM) of the Railocator System was built and tested on the Grand Trunk Western Railway in 1979-1980, and at South African Railways test laboratory in 1981.

Problems were encountered in the course of the South African testing which led to a critical evaluation of existing systems and of Glenayre's competitive position. It appears that although many systems have excellent performance in eliminating wrong numbers from the data base, none are particularly good at delivering the correct number under conditions of high environmental noise. Thus the opportunity existed to outperform competing systems in a critical area of system effectiveness.

It was on this basis that Glenayre decided to continue the development of Railocator, and good performance under high noise conditions was a primary objective. The addition of certain necessary features and the implementation of the transponder in VLSI technology were other major objectives.

1.2 Objectives

Railocator is an electronic system for labelling and reading identification numbers on railroad rolling stock. It comprises an inductively powered transponder mounted under the railcar, and an Interrogator Antenna mounted on the crossties between the rails. The Antenna both energizes the transponder and radiates a high frequency field. Binary data modulation is conveyed from the transponder by a two-state reflector. The modulated signal is received by the antenna and processed in a high-speed logic controller. The recovered information is either stored in the controller or output to a computer and/or printer.

Starting with the early EDM of Railocator, the objective of this project was to complete the development of a prototype RAILOCATOR. The major work was directed toward:

1. Improving the error control power of the system
2. Developing a cost-optimized transponder using custom LSI
3. Developing a field programming unit for programming transponder numbers.

Upon completion of this work, it was proposed to test a pilot RAILOCATOR System in co-operation with a unit train bulk commodity operation in Western Canada, leading to a benefit/cost analysis of RAILOCATOR applied to unit train operations.

The work to be performed consisted of the following tasks, and has been carried out in a manner consistent with the proposal "Further Development of Railocator An Electronic System for Railroad Automatic Car Identification," Issue 2, June 24, 1981.

1. Survey possible applications for a vehicle identification transponder in other transportation tasks such as automobile identification and bus identification.

2. Survey communications and frequency utilization regulation in major industrialized countries to ensure that no barriers exist which would prevent the use of the transponder in a potential market.

3. Prepare and submit for approval performance specifications for an improved automatic car identification system based upon passive transponder technology which will satisfy a maximum practical number of the transportation tasks which are identified. The specifications shall include:

   a) controller
   b) transponder
   c) interrogator
   d) field programming unit

4. Design equipment in response to the specification. The design shall include the following features:

   a) built-in diagnostics for controller
   b) custom LSI for transponder
   c) a quadrature detector for the interrogator

5. Construct prototype equipment and test under laboratory conditions.

6. Fabricate a total of 110 transponders, three interrogator/controller sets, and one field programming unit, for installation and evaluation in the Pacific Region of CP Rail under field operational conditions.

7. Make arrangements with CP Rail for a six month operational evaluation of the Automatic Car Identification (ACI) system in unit train service. This shall include installation of the equipment on the cars and at a suitable wayside location, and monitoring the performance of the system throughout the evaluation period.

8. Support the installation and evaluation of the system at CP Rail for a period of six months.

9. Collect and analyze data in cooperation with CP Rail.

This report describes the work done and the results achieved under each of the foregoing items.

2. POSSIBLE APPLICATIONS OF AN IDENTIFICATION TRANSPONDER

A survey of possible applications for an identification transponder in areas other than railroads has shown us a high level of interest mainly in the following sectors:

a) Automobile manufucturing industry.
b) Subway system.
c) Public works.

2.1 Automobile Manufacturing Industry

General Motors showed great interest in this product to be used on their production line. In fact, GM already has specifications for Automatic Vehicle Identification and plans to use this system on a large scale in its "Small Car Project" scheduled for completion in 1988 if available technology exists. (See Appendix A.)

2.2 Subway System

Subway system suppliers show interest in this technology as a main subsystem for future system such as automatic announcements which are needed but in practice are unfeasible with today's technology.

2.3 Public Works

This technology also interests people involved in public works. In fact, the system can be used by maintenance and inspection vehicles for automatic reading of mile posts and toll gates along highways.

2.4 Conclusion

This survey shows the following points:

1. The need for transponder technology exists.

2. The range of application is wider than only for railcar identification.

3. Our basic specification is in accordance with the general requirements which are:

   a) low cost
   b) small size
   c) not battery operated
   d) wide temperature range
   e) readability between one to four feet

3. COMMUNICATION AND FREQUENCY

It is pointed out in the document "Survey of Radio Communications Regulations in Countries Where ACI May Be Used," dated June 22, 1985 (Appendix B) that:

"All initial design work shall be with the objective of producing equipment that will satisfy the requirements of the US Federal Communications Commission (FCC) Specifications for unlicensed operation of low power data communications devices. Approval of the equipment for use in territories controlled by other national radio regulatory bodies will then be obtained on a case by case basis as the requirement arises."

The two frequencies selected to operate the Railocator System are 240 kHz and 915 mHz.

It will be seen from this report that the following regulations applied for these frequencies.

3.1 Regulation for 240 KHz

From US Federal Communication Commission, Rules and Regulations, Volume II, July 1981.

Part 15, subpart D - Low Communication Devices: General Requirements.

Section 15.111 Operations below 1600 kHz.

A low power communication device may be operated on any frequency between 10 and 490 kHz or between 510 and 1600 kHz subject to the condition that the emission of RF energy on the fundamental frequency or any harmonic or other spurious frequency does not exceed the field strength in the following table.

Frequency (kilohertz)	Distance (metres)	Field Strength (microvolts per metre)
10 to 490	300	$\frac{2,400}{F}$

3.2 Regulation for 915 MHz

From the same reference as stipulated in 3.1.

In Section 15.309 Emission Limitations

a) For a field disturbance sensor operating on any frequency listed in 15.307, the field strength of emissions on the fundamental shall be limited in accordance with the following:

Frequency (mHz)	Field Strength
915) 2,450) 5,800)	50,000 uV/m at 30 metres
10,525)) 24,125)	250,000 uV/m at 30 metres

b) Harmonic emissions from sensor operating in the bands centered on 915, 2,450 and 5,800 mHz shall not exceed a level of 160 microvolts per meter at 30 meters. Spurious emissions except harmonics shall be suppressed at least 50 dB below the level of the fundamental; however, suppression below 15 microvolts per meter at 30 metres is not required.

c) Harmonic emissions from sensors operating in bands centered on 10,525 and 24,125 mHz shall not exceed a level of 2,500 microvolts per meter at 30 meters. Spurious emissions except harmonics shall be suppressed at least 50 dB below the level of the fundamental; however, suppression below 15 microvolts per meter at 30 meters is not required.

NOTE: For pulsed operation, measured field strength shall be determined from the averaged absolute voltage during a 0.1 second interval when field strength is at its maximum value. Below 1000 mHz, the measurement bandwidth shall comply with the requirements set out in the American National Standards Institute Specifications C63-2-1963 and C63.3-1064. Above 1000 mHz the measurement bandwidth shall be 5 mHz.

4. SPECIFICATIONS FOR AN IMPROVED AUTOMATIC CAR IDENTIFICATION SYSTEM

In Appendix C there is a copy of the document "Automatic Car Identification," submitted on March 15, 1982.

This document shows the specification to a level sufficient to define the target requirements for the system. It covers the following subsystems:

a) general requirements
b) the transponder
c) the interrogator
d) the car detector
e) the controller
f) the field programmer
g) system requirements

This specification remains relevant and appropriate for work presently being considered. For example, a requirement statement and request for proposal issued by CP Railway in July 1985 is fully covered.

5. DESIGN FEATURES

The following design features have been studied, and specific work done with the objective that they be included in the final equipment:

a) Built-in diagnostics for controller.
b) Custom LSI for transponder.
c) A quadrature detector for the interrogator.

5.1 Built-in Diagnostics for Controller

Appendix D shows the ACI Controller Software Specification, February 15, 1983, Issue 2.

An RS-232 port will be available for diagnostics. All event data that is pooled will be output via this port in ASCII characters. Upon receipt of a polling signal, the Controller will store status information that will indicate detected equipment failures in any aspect of the Interrogator, Axle Detector, and Controller system. This will include:

- Interrogator Failure
- Axle Detector Failure
- Loss of Prime Power
- Loss of Battery Backup Power
- Memory Storage Overflow
- Controller Software Failure

The real time and date will also be output. It will be possible to set the Real-Time Clock via this port.

5.2 Large Scale Integrated Circuit for Transponder

The main objectives to develop a large scale integrated (LSI) circuit for the transponder are to reduce its unit price, its size and to raise the reliability level. Progress in semiconductor fabrication techniques since this project started has been such that it is appropriate to use very large scale integration (VLSI) technology.

5.2.1 The Unit Price:

As the transponder will have to be produced on a large quantity basis, it is then obviously important to diminish the number of components constituting it. Doing so, the manpower required to produce each unit will be proportionally lower and also as a consequence, the size of the unit will be reduced conceding a second level of material economy. After high R&D costs are recovered, price can be lowered to meet market competition.

5.2.2 Reduction of Size:

To reach a larger market with the transponder, the size is an important factor mainly for automobile production. As stated in the preceding paragraph, the use of VLSI will be a major factor of size reduction. Also as a secondary factor for volume reduction, it will be appropriate in the next transponder generation to use a filling dielectric in the transponder enclosure to reduce the height of the transponder.

5.2.3 The Reliability Level:

The life of the transponder is a major concern of the prospective customer. In fact, the transponder used in a railcar identification system will be of no practical utility if the mean transponder life is below 10 years. To reach an expected life higher than this figure, rule of thumb says that the calculated life for each component be at least over 30 years. This is another argument that emphasizes the necessity to reduce the number of components in the transponder. Ideally the transponder will comprise only one component, the VLSI device itself.

5.2.4 VLSI Specification

In order to establish the basic specification for the one chip transponder, a working model was design, built and tested from discrete components (Appendix E). The following parameters were then pointed out:

1. The operating voltage of the VLSI shall be of 2 volts or less, if possible.

2. The overall power consumption shall be less than 200 microwatts.

3. The zener "voltage limiter" shall be fixed to 5.6 volts with a power disipation of 0.1 watt. These three specifications are in addition to the general ones which are:

   a) All semiconductor components shall be integrated.
   b) Where possible, discrete components such as capacitors shall be integrated.
   c) A 64 X 1 field programmable matrix shall be part of the integrated circuit.

4. The input clock frequency shall be 240 kHz.

5. Operating temperature range will be -40°C to +70°C.

6. The projected life of the chip is 40 years.

7. For purposes of low power consumption and low operating voltage, CMOS technology will be used.

5.2.5 To achieve an expected life of 30 years and to be field programmable, the type of memory cell becomes an important concern. In fact, the only type of memory cells that can offer performance are of the fuse type.

If a dynamic RAM cell were to be used, it would have a data retention time which is dependent on the battery life. No supplier offers more than 10 years.

The memory cells which are electrically modifiable or can be erased by photon radiation or have magnetic retention cannot be used due to their relative sensitivity to environmental exposure.

5.2.6.3 The Fuse Type Cell:

The fuse type cell operations on the principle that the data stored in the cell has a value equivalent to the status of the fuse. The data is 0 or 1 if the fuse is blown or not blown.

Not all kinds of fuse cells can give an elevated mean time between failure. In fact, fuses made of nichrome show a phenomenon commonly referred to as "growback."* The reversal of the programming process such that a single bit will, after some time, go from the programmed state back to the unprogrammed state. The best technology known today to avoid the "growback" problem is the use of polysilicon link instead of Nichrome to produce the memory cell.

5.2.6 A prototype VLSI device was designed, fabricated and successfully tested in a "single-chip" transponder. Chapter 6 describes in detail the theory of operation of this transponder.

5.3 Quadrature Detector/Receiver

By nature the system depends upon receiving reflected waves from a moving antenna, and mixing them with directly transmitted waves. This causes apparent nulls in the radio field, by an effect similar to Rayleigh fading which can be encountered with any radio communication system. The problem is particularly severe because they wave length is small compared with the separation of the antennae, and the separation is constantly changing. The nulls are eliminated by use of a quadrature receiver which ensures that a detectable signal is received at all times.

6. THE VLSI SINGLE CHIP TRANSPONDER (Theory of Operation)

The single-chip transponder operates in conjunction with a tuned magnetic receiving antenna for DC power and synchronization. The DC power requires an external diode and a small filter capacitor. Voltage regulation is accomplished on the chip. The synchronization requires an external current limiting capacitor. The UHF reflector antenna may be connected directly to the integrated circuit since the modulating elements, a pair of varactors, have been implemented on-chip. A block diagram of the transponder is shown on Figure 1.

The incoming clock signal, normally a clipped 240 KHz sinusoid, is converted to a square wave by the input squaring circuit, Figure 2. This circuit embodies hysteresis in order to minimize the probability of spurious clocking which might be occasioned by antenna noise pickup. The squared clock signal passes through an eight-stage frequency divider whose outputs generate all clocks in the code-generation portion of the chip. See Schematic Figure 3.

The main memory of the chip holds a 64-bit code comprising a 10-bit frame-sync preamble, and a single parity bit. Because of the particular encoding technique, the parity bit as well as the preamble are invariate in memory, while the remaining 53 bits are field-programmable. Even though the parity bit does not need a programmable memory location, it does convey a check bit when transmitted.

The memory is configured as a 64-bit vector. All locations in this vector are addressed individually by means of a tree-type circuit having as address inputs Q3 through Q8 and their complements from the frequency divider as shown in Figure 4. Each memory cell (see Figure 5) employs two polysilicon fuses in order to minimize power drain. Only one fuse per cell is left intact after programming. A particular memory location is read by precharging the memory address tree, and then permitting it to discharge through the intact fuse within the addressed memory cell. If the intact fuse is the one connected to VSS, the discharge is sensed and a zero is latched. If the intact fuse is the one connected to VDD, no significant discharge takes place and a one is latched. Figure 6 shows a schematic of the programming logic.

The resulting data readout is DPSK encloded by means of an XOR output circuit which drives the pair of on-chip varactors. The latter modulate the reactance of a UHF reflector antenna, which produces phase modulation in an incident UHF signal whose frequency is near the self-resonant frequency of the reflector antenna.

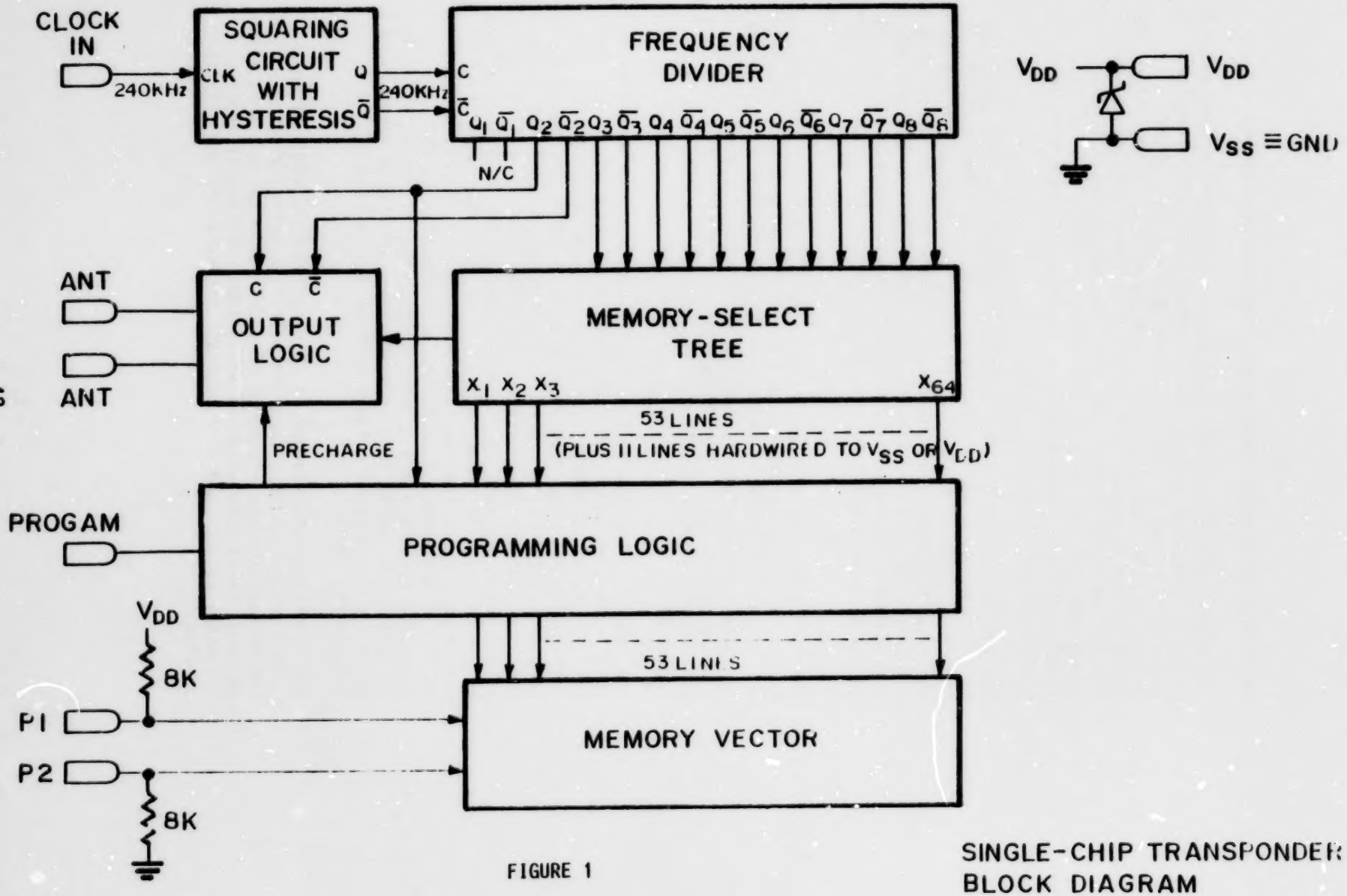


FIGURE 1

SINGLE-CHIP TRANSPONDER BLOCK DIAGRAM

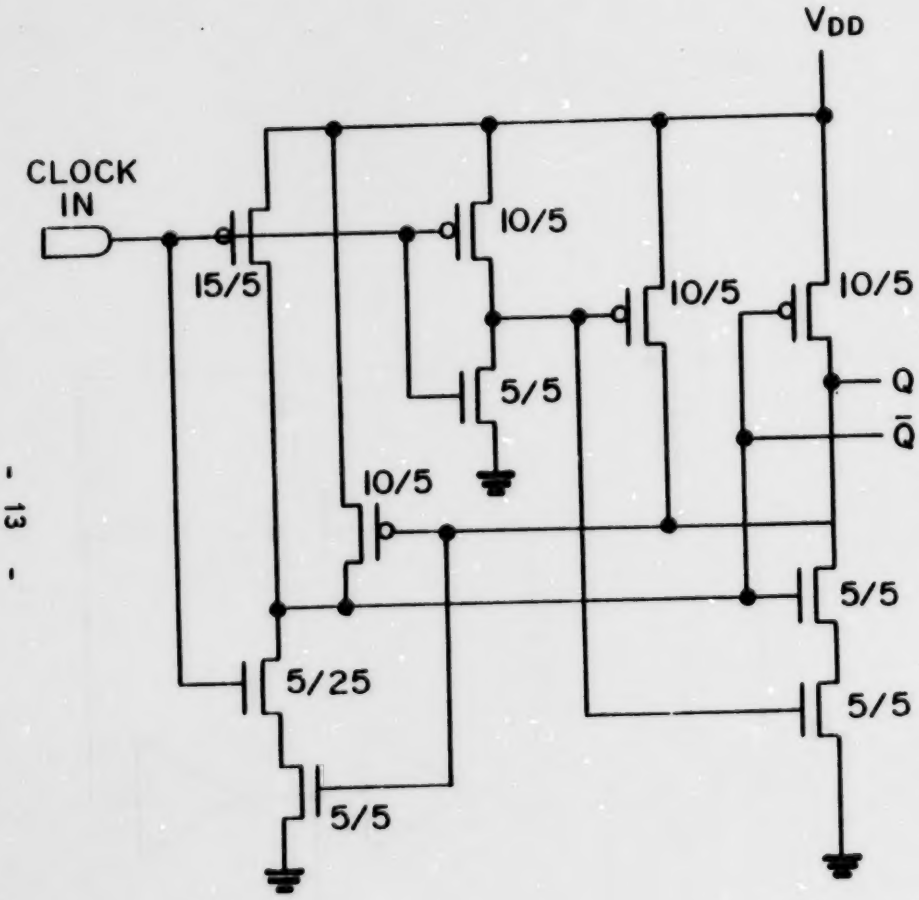


FIGURE 2

SINGLE-CHIP TRANSPONDER
SQUARING CIRCUIT

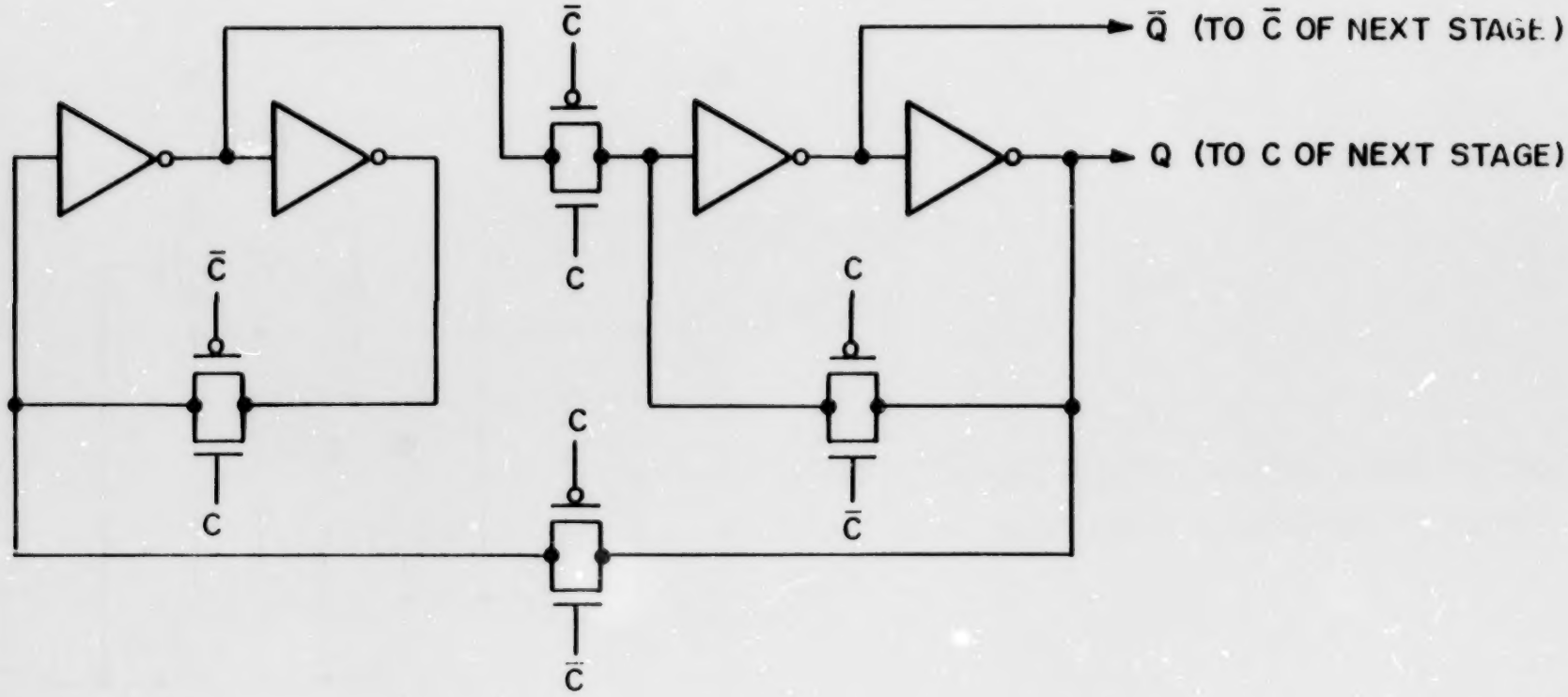


FIGURE 3

SINGLE-CHIP TRANSPONDER
FREQUENCY DIVIDER STAGE
(ONE OF EIGHT)

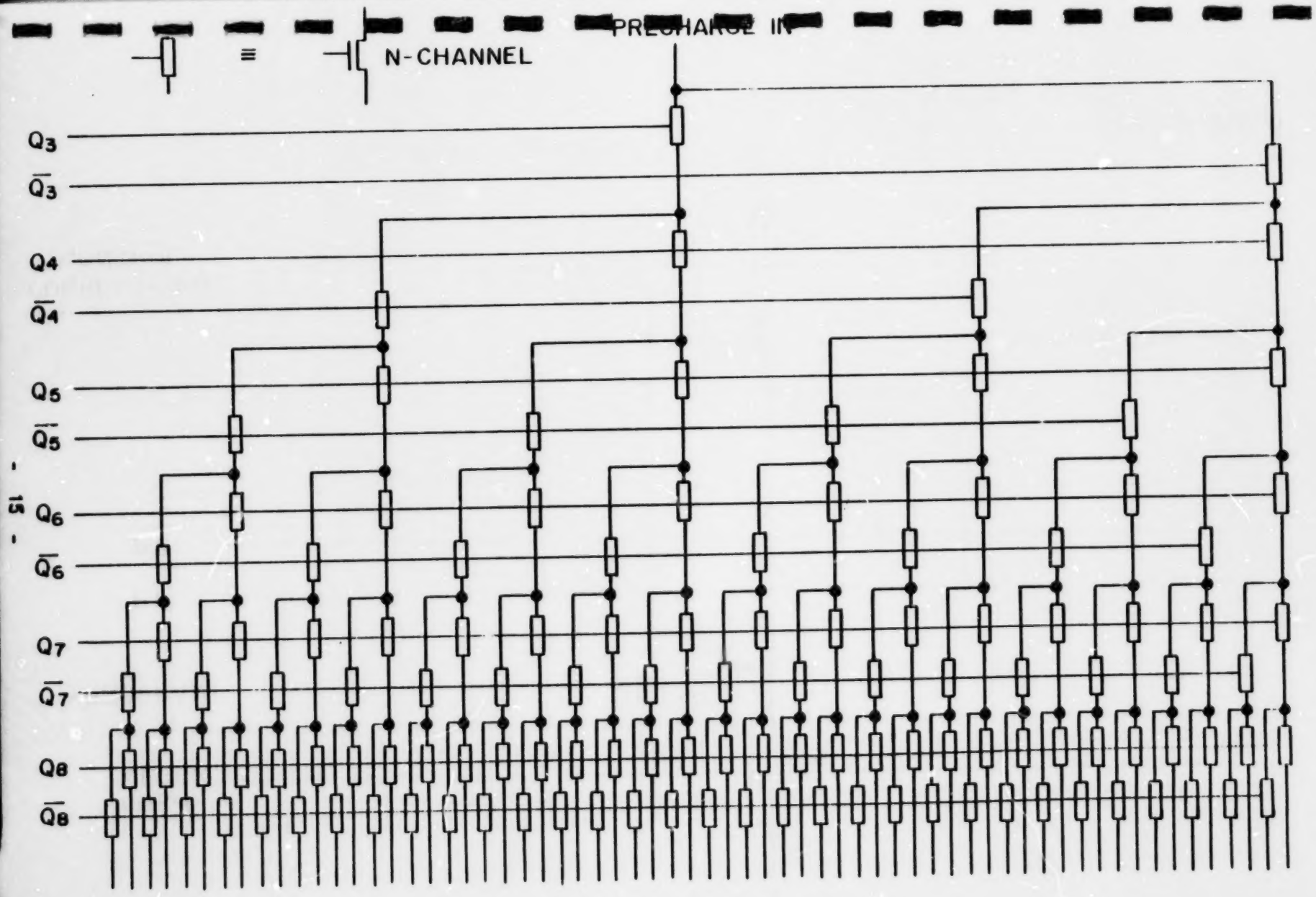


FIGURE 4

SINGLE-CHIP TRANSPONDER
MEMORY-SELECT TREE

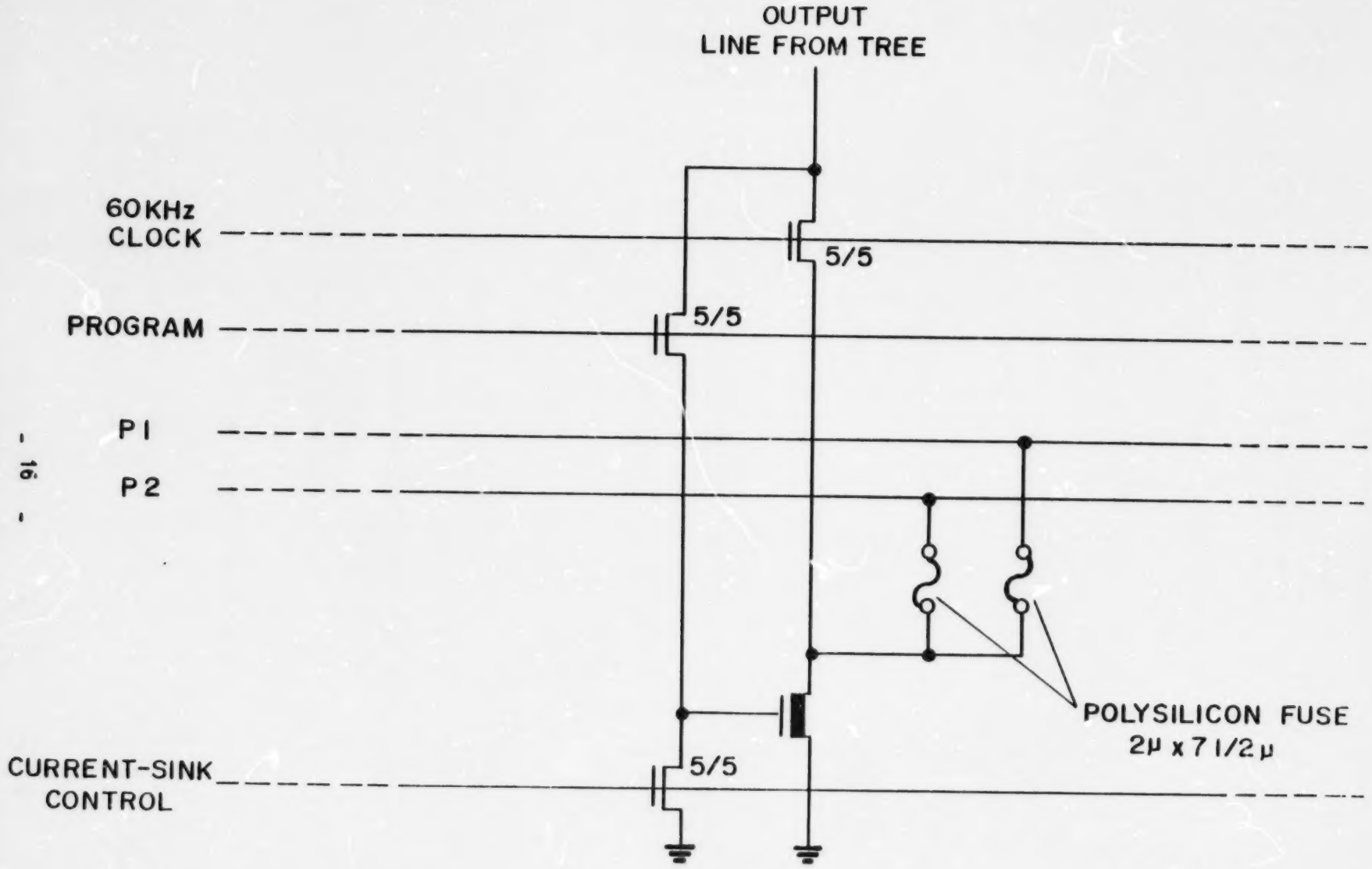


FIGURE 5

SINGLE-CHIP TRANSPONDER
MEMORY CELL
(ONE OF 53)

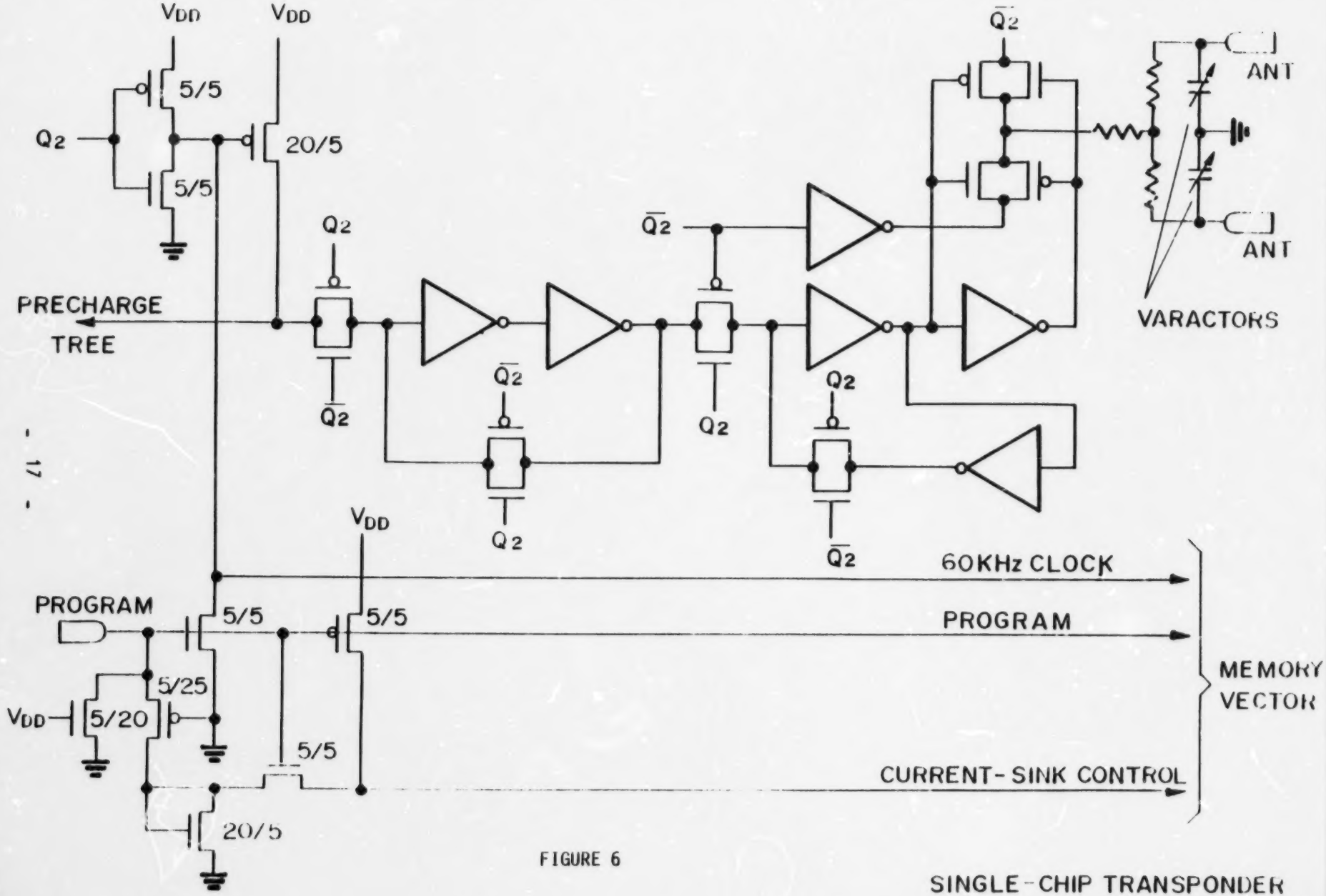


FIGURE 6

SINGLE-CHIP TRANSPONDER
OUTPUT, PROGRAMMING LOGIC

The polysilicon fuses which carry the code information are programmed by means of a 20 mA current which is switched by a programming transistor within each cell within the memory vector. Each fuse has dimensions 2 microns by 7.5 microns. Field programming is accomplished by connecting the PROGRAM pin to VDD. This diverts the output lines from the memory-address tree from the fuses to the gates of the corresponding programming transistors. The circuit is clocked and data are entered after the preamble has been seen on the output (antenna) pins. Data entry is accomplished by connecting either P1 or P2 to VDD, thereby determining which fuse within a cell blows, and thereby whether a cell conveys a "one" or a "zero." The programming logic circuitry ensures that all but one of the programming transistors are held off at any one time.

7. THE QUADRATURE RECEIVER

7.1 Theory of Operation

The function of the receiver is to recover the 60 data kHz signal from the 915 mHz modulated carrier signal. When the 915 mHz carrier is reflected from the transponder, it is modulated by the 60 kHz code from the transponder. If the received 915 mHz modulated signal is simply mixed with the reference 915 mHz signal, nulls will be observed periodically as the transponder moves over the interrogator. This happens when the modulated signal and reference signal are 90° out of phase. To eliminate these nulls, a quadrature receiver with two outputs (I and Q) is used. When one output channel is at its minimum, the other is at its maximum so that at least one channel gives a good signal at any instant.

The quadrature receiver is built on a special printed circuit board (RT/Duroid 5870) using microstrip technology. It has two inputs: the reference local oscillator (LO) and the signal received by the 915 mHz receiving antenna (RF). The LO signal is passed into a branchline coupler which splits the LO signal into two signals of equal magnitude and 90° out of phase. The RF signal is passed into an in-line power divider which splits the RF signal into two signals of equal phase and magnitude. The LO and RF signals are then mixed by a double-balanced mixer (TFM-2). The outputs of the two mixers are the signals I and Q.

7.2 Receiver Circuitry

For a microstrip circuit, the impedance and wavelength of the line is affected by the dielectric constant, the width and thickness of the microstrip substrate.

7.2.1 RT/Duriod 5870:

This printed circuit board has very stable characteristics in a harsh environment. The characteristics useful in the calculations are:

Dielectric constant (ϵ) = 2.33
Thickness of substrate (h) = 1/16" = 1.5875mm

7.2.2 Branchline Coupler:

The branchline coupler is a 4-port device (see figure 7). Each of the arms is a quarter-wavelength long. The impedances of the series arms and parallel arms are different for matching purposes.

Let Zin = input impedance
Zout = output impedance
Zs = impedance of the series arms
Zp = inpedance of the parallel arms
W = width of the microstrip line
h = thickness of the microstrip line
m = wavelength of the microstrip line

For Zin = Zout, then Zp = Zin and
Zs = (Zin)(Zin)/2

Because Zs is essentially a quarter-wave transformer.

Now frequency (f) = 915 mHz

Free space wavelength (o) = (3.0 x 10)/f
= 0.32787m

The calculations are as follows:

ARM	Z(ohm)	W/h	W(in)	W(mm)	o/ m	m/4(in)	m/4(mm)
SERIES	35.4	5	5/16	7.94	1.45	2.2726	56.5
PARALLEL	50	3	3/16	4.76	1.42	2.2256	57.7

Where W/h and o/ m are found from Wheeler's graphs.

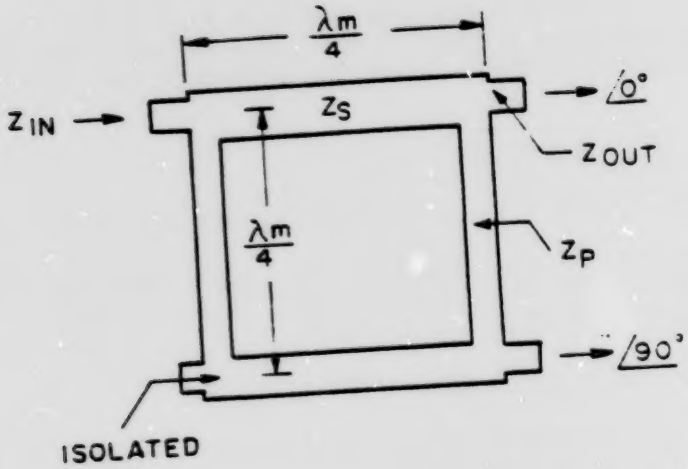


Figure 7 - Branchline Coupler

7.2.3 The In-line Divider:

The in-line power divider consists of two arms of quarter-wavelength transformers (see figure 8). The resistor is to absorb unequal power in the two arms but it can be eliminated in this application. Using the same notation as before:

$$Zs = \sqrt{(Zin)(Zout)(2)}$$

For Zin = Zout = 50 , the calculations are as follows:

ARM	Z( )	W/h	W(in)	W(mm)	o/ m	m/4(in)	m/4(mm)
IN	50	3	3/16	4.76	1.42	2.2256	57.7
SERIES	70.7	1.6	0.1	2.54	1.4	2.305	58.55

7.2.4 The Double-Balanced Mixer (TFM-2):

This double-balanced mixer has extended operating temperature range (-55°C to 100°C) and is wideband (0 to 1 gHz). Each of its input and output ports has a nominal characteristic impedance of 50 .

It must be noted that in the above calculations, the frequency effect, function effect and end-effects have been neglected because they are not important at this frequency.

The complete receiver consists of two TFM-2's, a branchline coupler and power-divider (see Figure 9). Coupling capacitors connect the 915 mHz signals to the microstrip circuit, and their values are about 100 pf. Since the TFM-2's do not present exactly 50 to the input signals, resistors connected to ground are used to match the microstrip line to the mixer. The resistor value can be anywhere between 51 and 100 , and the optimum should be found by experiment.

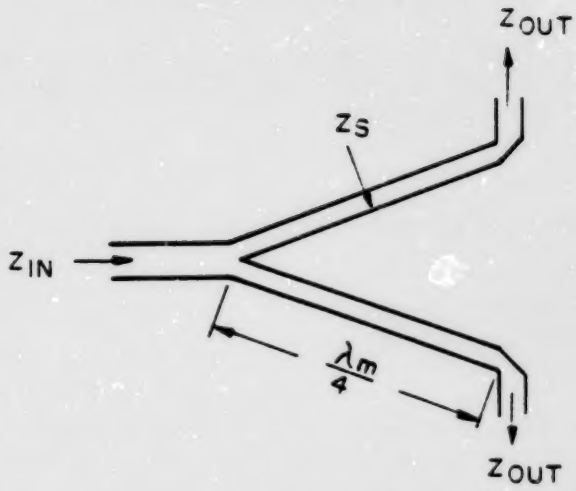


Figure 8 - The In-Line Power Divider

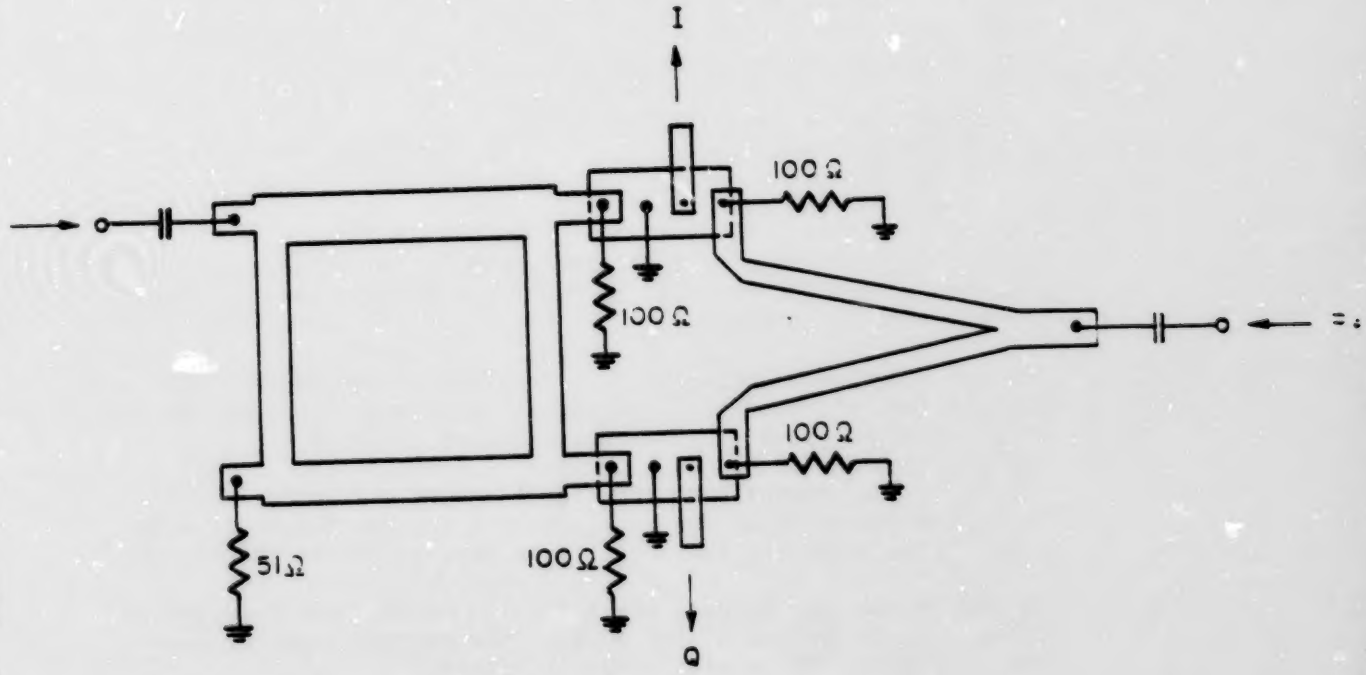


Figure 9 - The Quadrature Receiver

8. PRODUCTION OF A PROTOTYPE AND LABORATORY TEST

The objective of this section of the contract was to realize a prototype and test it to prove the validity of the operating principles in the laboratory.

8.1 Architecture

The system consists of four subsystems (see Figure 10):

a) The transponder.
b) The interrogator antenna.
c) The decoder unit (controller).
e) The computer.

The principle of operation is that a low frequency "240 kHz" field is generated by the decoder unit and transmitted to the transponder through the interrogator. This 240 kHz magnetic field radiation is received by the transponder where it is rectified and filtered to energize the transponder. A part of that energy is also extracted before filtering to synchronize the transponder clock.

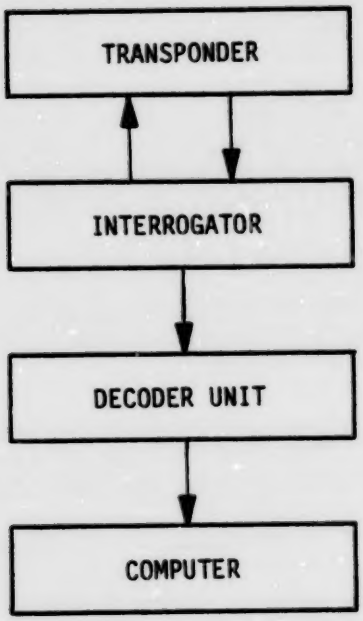
A second unmodulated frequency of 915 mHz is generated by the decoder unit and transmitted to the transponder through the interrogator. The transponder modulates the reflectance of its antenna by the use of a variable capacitor, (high-speed varactor) a part of the 915 mHz is reflected back to the interrogator modulated. The message which is modulated is a string of 64 bits. This string is composed of:

10 bit for synchronization
35 bit for code
18 bit for CRC
1 bit for parity

The transmission rate of that binary modulation is an exact fraction of the 240 kHz used to power the transponder. In fact, the kHz rate is 60 kbaud.

The reflected modulated signal is received at the control box through the interrogator. Two signal paths at 90° quadrature are mixed with the local oscillator (to ensure constant signal input), then fed through an amplifier, detector, and digital filter. Once demodulated, the signal enters the decoder module. The synchronization of the signal in the decoder module is made possible by using the same oscillator that generates the 240 kHz.

Inside the decoder module, the signal is decoded and rejected if false. At the output of the module, the message contains only the 35 bits of the 64 bits original message.



System Architecture

Figure 10

The code is then passed to a microcomputer which acts as an intelligent buffer-amplifier. It stores the numbers as required, handles additional logic such as detection (if fitted) and formats the information as required for output. The computer can manipulate the code as needed but this depends on the content of the code.

8.1.1 Configuration:

Figure 10 shows interrelation between the components that constitutes the ACI.

8.1.2 Internal Interfaces:

In our system there is one type of interface. It is the radio link interface between the transponder and the interrogator.

8.1.2.1 The Radio Link Interface

The radio link interface is used to communicate between the interrogator and the transponder. For the system, we have used three links which are:

a) 240 kHz from interrogator to transponder
b) 915 mHz from interrogator to transponder
c) 915 mHz from transponder to interrogator

8.1.2.2 240 kHz from Interrogator to Transponder

This link is used to transmit energy to power up the transponder and to generate the baud rate. This link is a magnetic field coupling type.

This field is generated by an array of magnetic loops perpendicular to the rail. This will allow the following capabilities:

1. An out-of-centre tolerance for the transponder of 20 centimeters. See Figure 11.

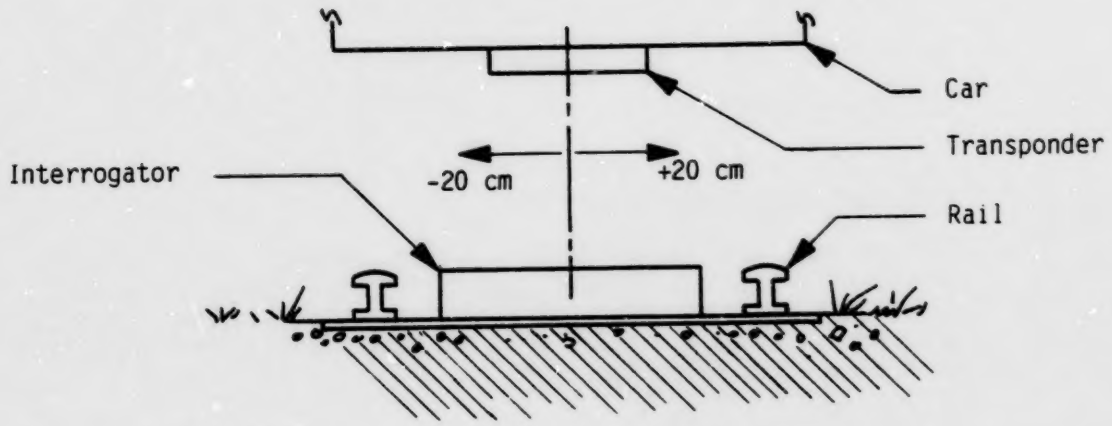


FIGURE 11 Transponder/Antenna Dimensional Tolerance

2. A minimum span angle for 240 kHz transmission. This will reduce the minimum distance between two transponders.

The length of the antenna is directed by the following values:

a) The maximum speed of the train is 210 km/h.
b) A minimum of 15 transmissions is required.
c) The message contains 64 bits.
d) The transmission rate is 60 kBauds.

A simple calculation shows that a minimum length of .93 metres is required. We built the antenna to a length of 1.66 metres.

Figures 12 and 13 show the mechanical configuration and electrical details respectively.

It is recommended that the distance minimum between two transponders never be less than 3 meters.

8.1.2.3 915 mHz from Interrogator and Transponder

This frequency is a low power signal transmitted to be modulated and echoed by the transponder. This signal will be serviced by a transponder only when it is energized. For that reason the size of the field must be at least the same as the 240 kHz field.

8.1.2.4 915 mHz from Transponder to Interrogator

This link is intended to communicate the message from the transponder to the interrogator. The receiving antenna will have the same characteristic as the 915 mHz transmitting antenna.

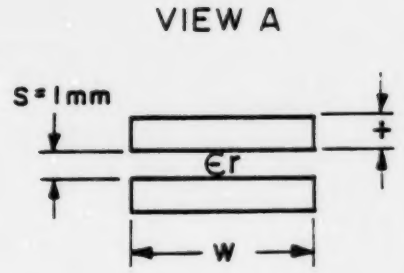
See Figure 4 for high frequency antenna details.

8.1.2.5 915 MHz Antenna Dimension

The transmitting and receiving antennae are designed and constructed in the same manner.

Each antenna consists of an array of 10 elements. The dimensions are based on the wave length, lambda. Each element is lambda/2 long, each array is separated by a distance of lambda/2 and the antenna is lambda/4 distant from the back plane. The diameter of each element is lambda/20.

ANTENNA CONFIGURATION



TWO-PLATE LINE CONFIGURATION

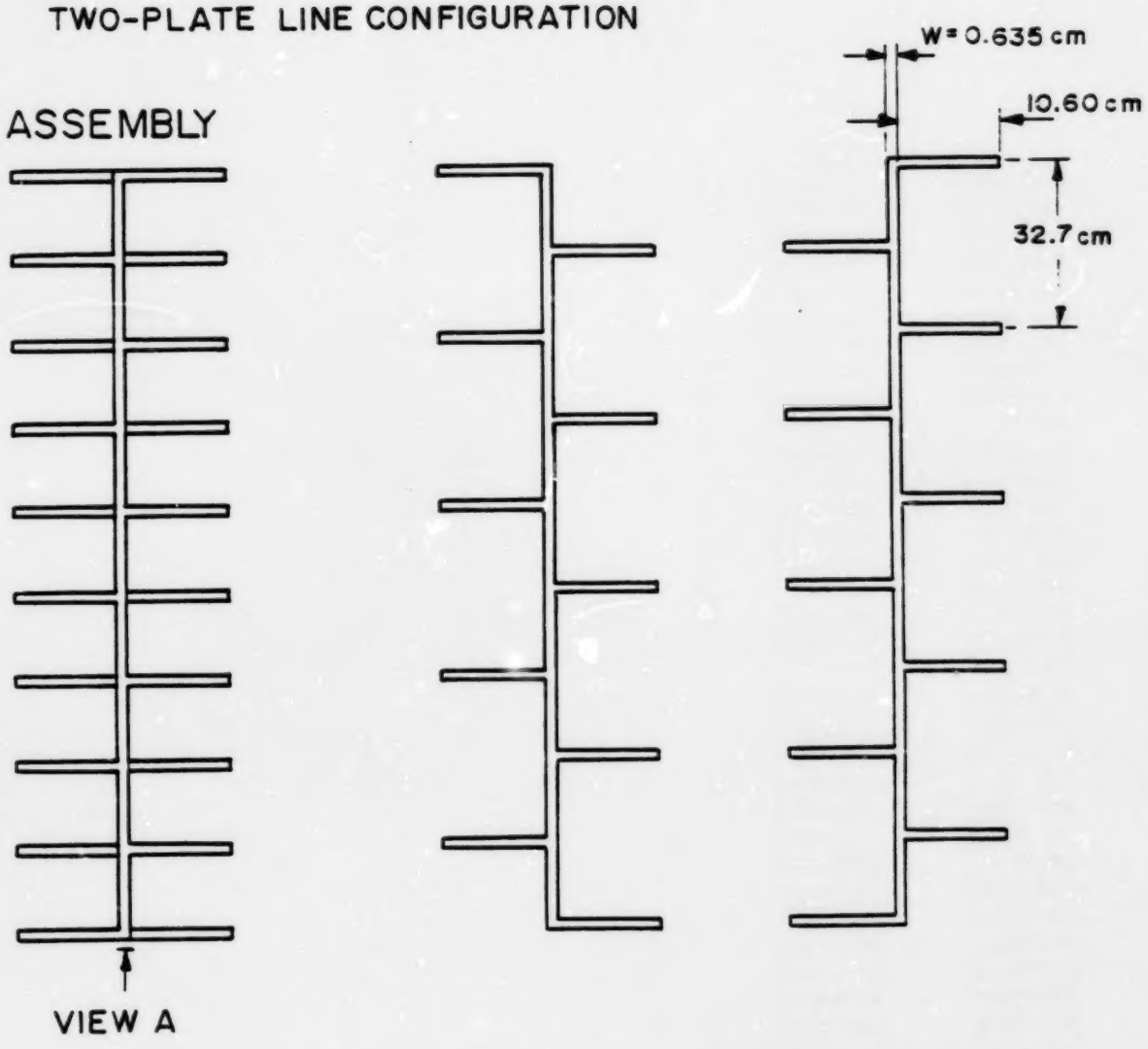


FIGURE 12

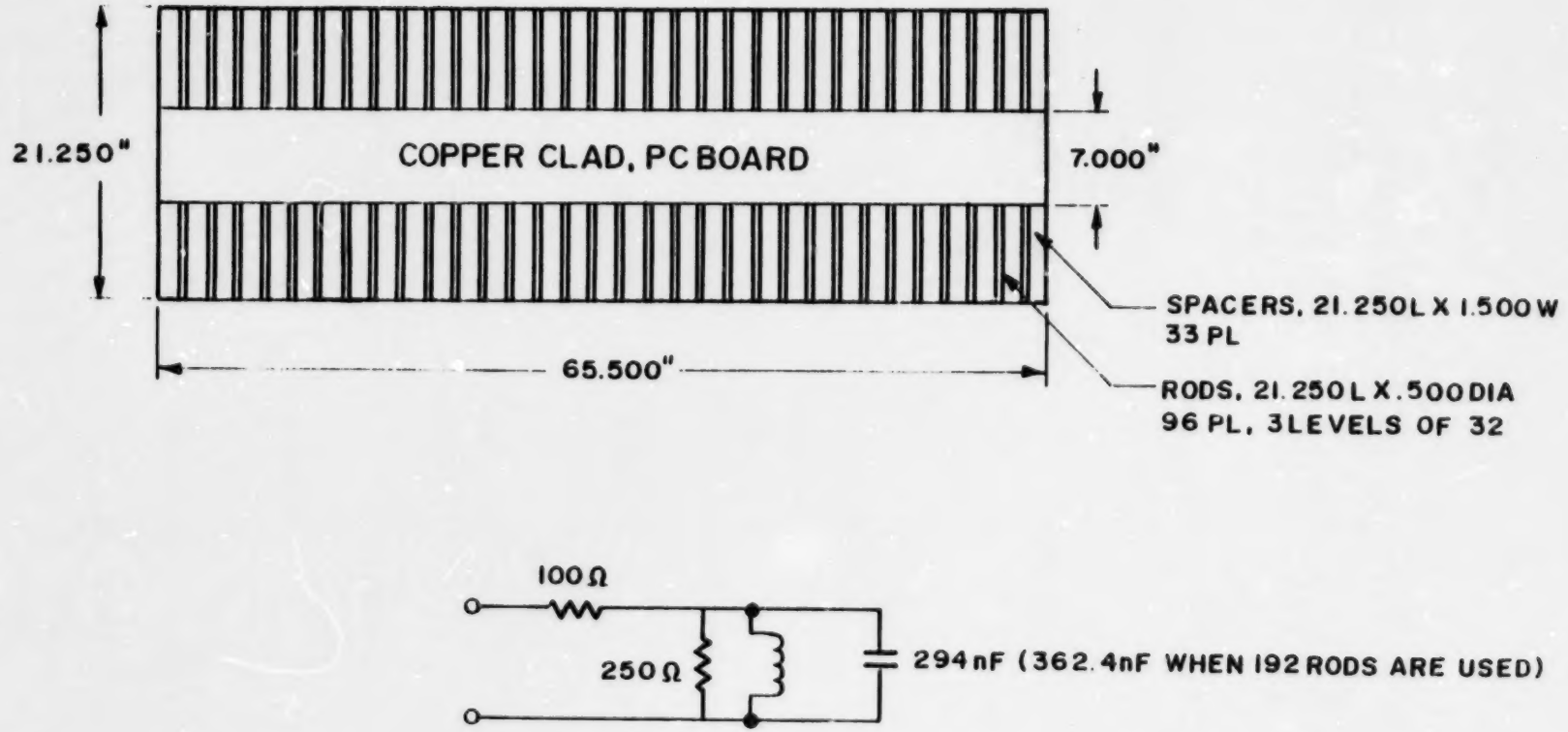


FIGURE 13 ANTENNA ELECTRICAL DETAILS

8.2 Description of the Decoder Unit

The decoder unit is composed of a series of sub units which together fulfill the following functions:

1. An uninterruptible power supply that permits the functioning of the interrogator antennae, the decoder unit and the wayside unit.
2. A 915 mHz oscillator.
3. A 240 kHz power amplifier.
4. 915 mHz receivers.
5. Signal demodulators.
6. Reader.
7. Communication link interface.
8. Wheel detector subsystem.

8.2.1 Theory of Operation:

Energy to power the transponder is derived from the 240 kHz magnetic field established by the loop antenna in the rack-mounted interrogator. The interrogator gets approximately 600 milliwatts of drive at 240 kHz from a power amplifier in the ACI reader. Most of this power is dissipated in the resistance of the transmitting antenna, and the amount of radiation falls within the FCC Rules and Regulations, Part 15, Subpart D, Section 15.111, for certification for operation with no individual license.

Signalling is accomplished by a two-way UHF link. Power at 915 mHz comes from a buffered oscillator in the reader, passes through a matching circuit which splits the energy among the antennae and mixers which are to be excited, and lastly passes through a bandpass filter before reaching the transmit antenna. This antenna is a multi-element driven broadside array, and the one milliwatt of transmitted energy is radiated with a maximum energy density at the interrogator surface of less than one microwatt per square centimeter. This extemely low level of energy density satisfies the most stringent personnel safety requirements, as well as the FCC Rules and Regulations, Part 15, Subpart F, Sections 15.305(b), 15.307 and 15.309 for certification for operation with no individual license. The radiated 915 mHz energy is partly reflected by a near-resonant antenna element inside the transponder.

This element has its resonant frequency modulated by the transponder's code generator driving a varactor with a DPSK signal. As a result, the small amount of 915 mHz energy which is reflected is phase-modulated. This phase-modulated element of the 915 mHz field is received by the interrogator, through another multi-element driven broadside array. From the interrogator, the signal passes through a bandpass filter to the UHF receiver in the reader.

The bandpass filters in the transmission lines of both UHF receive and transmit antennae are interdigital arrays which do a good job of rejecting induced currents from nearby lightning strikes which might otherwise damage the reader electronics.

The UHF receiver uses for its reference oscillator the same 915 mHz buffered oscillator which was used as a transmitter. Accordingly, the received signals are synchronously detected by the mixer and are relatively insensitive to oscillator frequency drift. The mixers are passive diode bridge devices which actually get substantially more oscillator drive than the transmit antenna does. The received signal comes in at an unknown and variable phase with respect to the local oscillator, depending on the distance between the transponder's reflector and the interrogator antennas. To ensure that the signal is received continuously without phase nulls as a train passes, two receivers in quadrature are used.

The "in-phase" channel is driven by the buffered oscillator directly, while the "quadrature" channel is driven by the same oscillator phase-shifted by 90°. At least one mixer will always provide a good signal, providing of course that a transponder is within range. The ouput from the mixers is amplified and bandpass-filtered.

The filtered signal is then squared and DPSK-demodulated. Simultaneously, the filtered signal is further high-pass-filtered and peak-detected. The relative values of the peak-detected signals from the in-phase and quadrature channels give an indication of the instantaneous relative signal-to-noise ratio of the signal as received by the two receiver channels. A selector circuit constantly monitors the two peak-detected signals, and when one exceeds the other by a predetermined threshold, switches the DPSK-demodulated output from the higher-SNR receiver channel to the receiver output for further processing.

The signal now passes to a digital filter which effectively slew-rate limits the signal before threshold-detecting it. The digital filter thus effectively minimizes transition noise at the start and end of individual bits.

At this stage, we have a fully demodulated data stream, ready for the error-control logic. Many bit errors can be expected when operating at high ambient noise levels (such as might be occasioned by lightning storms or electrified track), especially when the transponder is just coming into range. The data rate of 60 kbits per second permits a full data frame to be received in approximately one millisecond, and permits at least 30 frames even when a transponder passes at a velocity of 200 km/hr. We use the available data redundancy as fully as possible to extract valid information from currupted data. We do this by averaging 15 frames to generate a data stream with a much lower bit error rate.

The data stream which the UHF receiver passes to the error control logic is not accompanied by either a bit sync or frame sync clock. Bit sync clocks derived from the received signal become very jittery during periods of high noise, to the point where the clock becomes the limiting factor in valid data reception. In order to optimize the effectiveness of averaging 15 frames of received data, especially in periods of high noise when such averaging is most useful, it was decided not to derive a bit sync clock from the received signal. Instead, four quadrature clocks at the precise signal frequency are derived from the reader's main crystal reference.

This same crystal reference also synchronizes the transponders' code generator through the interrogator's low-frequency magnetic field. Clearly, at least two of the quadrature clocks would be virtually ideal bit sync clocks. Since we do not know a priori which are closest in phase to bit sync, we run four error controllers in parallel, one with each of the attempts at bit sync. This requirement is well beyond the speed ability of presently available microprocessors, given the data rate of 60 kbits per second. With a hardware implementation, however, the four-fold increase in processing required to extract bit sync in this optimal way is easily achieved by multiplexing and running the logic circuits at four times the bit rate.

The principal additions to hardware are the added shift register sections required for the signal information being simultaneously processed. In order to determine which "bit sync" channel holds good data, we simply do a parallel check on agreement between adjacent "bit sync" channels. If one channel synchronizes so close to the bit edges to cause an erroneous data stream, it is extremely unlikely that the channel having a bit sync which is 90° advanced or delayed will have identical errors. Conversely, two channels with bit sync separated by 90°, but comfortably away from the bit edges are very likely to agree.

The multiplexed parallel approach which was taken to optimize bit sync was extended further to allow the same error control hardware to handle four independent channels of data. Again, it is simply necessary to multiplex at a high rate to ensure that the logic circuits work fast enough, and appropriately extend the shift registers. The input to the error-control logic is now sampled at 960 kHz, allowing 16 samples for each bit interval. These 16 samples comprise four "sub-bits," one for each of the "bit sync" channels, from each of four independent interrogators. These might be mounted on four tracks in a railyard.

It happens that there is a very practical reason to multiplex interrogators. The very low data error rates achievable by our error-control logic can, in certain circumstances, be exceeded by the statistically predictable hardware failure rate. Clearly, passing four channels of data through a given error controller enhances the hardware failure rate by a factor of nearly four.

The multiplexed signal which samples each of the four channels at a rate of four samples per bit is fed to a 14,337-bit shift register, clocked at 960 kHz. This shift register has 15 taps separated by 1,024 locations each. At any instant, its output represents 15 samples taken at corresponding time slots of 15 consecutive frames on one interrogator channel. A latch running at a clock rate of 240 kHz selects only those 15-sample combinations coming from one channel.

This single channel is monitored for two complete frame intervals, approximately 2.13 milliseconds. Then, by phase-shifting the 240 kHz clock by 90°, the next channel is monitored for two frame intervals. Note that, although subsequent error control is frame-discontinuous, the sub-bit averaging is continous on all four channels. Thus, when a given channel is monitored by subsequent circuitry, the signals used are all of the 15 previous frames from that channel. Since a complete routine for all four channels takes eight frame intervals, the error checking is done on overlapping frame sets for further redundancy. Thus, on a given forty-frame sequence, the averages considered might be:

1) Frames 1 through 15
2) Frames 9 through 23
3) Frames 17 through 31
4) Frames 25 through 39

The 15 corresponding sub-bits output by the latch are presented simultaneously to two circuits: a 8/15 majority logic circuit which outputs the bit average, and a "greater than 12/15 agreement" circuit which outputs what we term the bit structure. The latter parameter is a very useful one to enable the processor to distinguish signal from noise. Clearly, the result from averaging 15 bits of noise is still noise. Checking whether enough of these 15 samples are in agreement yields a statistical indicator of the signal-to-noise ratio. If most of the bits in a 64-bit frame are derived from samples which showed good agreement, the data may be considered reliable enough to go through further error checks. If, on the other hand, many or most came from samples which showed poor agreement, the data may be rejected as unreliable, whether or not they happen to pass other error checks.

The bit average and the bit structure are now interlaced onto a 512-bit shift register. At the rate of four bit-average samples and four bit-structure samples per full data bit, this shift register will hold one full 64-bit data frame. Accordingly, it is tapped at intervals of eight sections. During the time when data samples appear at the output taps (for a duration of 2.08 microseconds) the following checks are done simultaneously in logic:

1) The frame sync is checked by a 10-bit flag detector which checks for a pattern "1000000001" on bits 1 to 10.
2) The BCH checker compares the interleaved BCH check code on bits 11, 12, 17, 18, 22, 27, 28, 32, 37, 38, 42, 47, 48, 52, 57, 58, 62 and 63 with the code which would be expected from the 35 received data bits in the remainder of the bits from 11 to 63, according to the modified and rearranged 63,45 BCH code employed.
3) The parity bit 64 is compared with that expected from the data and BCH bits 11 through 63.
4) The presumed data bits, interleaved in bits 11 through 63 as described in (2) above, are compared with those received in the previous bit sample (4.17 microseconds earlier) and latched. If the two data words are identical, bit sync is assumed to be acceptable.
5) The latched result of the previous structure test (described below) is checked for acceptability.
6) A timing circuit in the channel control is monitored to indicate whether there is an overlap of channels in the 512-bit register. Only with no such overlap can reliable data be extracted.
7) If checks (1) through (6) above all pass simultaneously, the output control circuit and data latch are activated. These strip the latched data from the flag and error control bits, and output the data, byte by byte, onto a data bus in an orderly fashion at 167 microseconds per byte.

During the next 2.08 microseconds when the structure samples appear at the shift register outputs, a logic circuit checks that, of the 64 samples, at least 40 are positive. This would indicate that at least 40 bits out of the 64 had better than 12 out of 15 agreement in their samples, indicating acceptable signal-to-noise ratio for reliable data extraction.

8.3 The Computer

For the purpose of the test, the computer was an "off the shelf" computer based on the Z80 microprocessor.

Its main job was to receive the code from the decoder, affix to this code the time, check the validity of the received code and print out the data, or as required, give the count of the transponder correctly read and the count of the transponders that have passed over the interrogator.

8.4 Laboratory Results

The results of the laboratory tests in ambient noise conditions and with added data corruption are given below.

TESTS IN AMBIENT NOISE

Date	Range	Velocity (km/h)	Number of Passes	Bit Errors Added	Misses	Errors
Oct 1	38"	200	33,344	0	0	0
Oct 1	38"	204	200,874	0	0	0
Oct 1-4	38"	200	2,120,382	0	0	0
Oct 4-5	38"	30	79,214	0	0	0
Oct 5	38"	70	41,377	0	0	0
Oct 8	39"	200	3,000,696	0	0	0
Oct 18	44"	200	93,528	0	0	0
Oct 19-22	44"	204	2,260,152	0	0	0
Oct 22-25	38"	200	2,098,986	0	0	0
Oct 25	38"	200	104,878	0	0	0
Oct 25	35"	200	97,828	0	0	0
Oct 26-Nov 2	30"	200	5,518,752	0	0	0
Nov 3-Nov 4	42"	200	534,632	0	0	0

Total Number of Passes: 15,184,640
Total Misses: 0
Total Errors: 0

TESTS WITH ADDED DATA CORRUPTION

Date	Range	Velocity (km/h)	Number of Passes	Bit Errors Added	Misses	Errors
Oct 6	38"	204	800,632	6.25%	1	0
Oct 15-16	44"	200	722,488	6.25%	1	0
Oct 16-18	44"	200	1,002,344	6.25%	1	0
Oct 5	38"	204	40,342	12.50%	0	0
Oct 5	38"	204	111,306	12.50%	1	0
Oct 12-15	39"	100	1,142,292	12.50%	0	0
Oct 15	44"	200	19,678	12.50%	2	0
Oct 5-6	38"	204	512,220	25%	over-flow	0
Oct 6	38"	204	2,100	25%	over-flow	0

Total Number of Passes: 4,353,382
Misses: about 1 in 1,000,000 up to very high levels of noise (12.5%) beyond which it is not reasonable to expect data recovery without substantial misses.

Total Errors: 0

Total Number of Passes (both sets of tests): 20,538,022
Total Errors: 0

9.0 FIELD TESTING

Items 6 through 9 of the contract statement of work were not completed for the following reasons:

1. The rework required on the VLSI transponder chip to eliminate the problems discovered in the prototype chips was costly and would exceed the project budget.

2. No potential customer could be found who had sufficient interest in the potential results of this development project to commit in any way to purchase the system if development was successfully completed.

Work was stopped while the prospects and viability of RAILOCATOR as a commercially successful product were investigated. At this time the one major purchaser known, South African Railways, had drastically reduced the scope of their project and had awarded the installation of a pilot system to a South African firm.

Since the objective of the project was to develop a commercially viable product, and since significantly more funding would be required to complete development, it was decided to reassess the situation.

It evolved, after several months, that Canadian National were prepared to assist in field testing Railocator. They would not fund the development or testing but would consider a commitment to purchase a system if field testing was successful. After a considerable passage of time, CN concluded that no commitment to purchase would be made until after the field demonstration, but that a significant purchase at that time was possible.

With the amount of technical work remaining to be done, and no purchase committment it was apparent that testing of fully productionized equipment was not possible with the project funds remaining. A field test was proposed using interim equipment consisting of the existing engineering development model (EDM) of the wayside equipment, refurbished to make it suitable for field conditions, and approximately 100 transponders manufactured with discrete components rather than the VLSI chip.

This proposal was acceptable to Canadian National but not to the funding agency. In the discussions that followed it was decided to terminate the project at its current state of completion.

APPENDIX A

"GENERAL MOTORS SYSTEM CRITERIA FOR AUTOMATIC VEHICLE IDENTIFICATION"

GENERAL MOTORS ASSEMBLY DIVISION

AUTOMATIC VEHICLE IDENTIFICATION

(A. V. I.)

SYSTEM CRITERIA

G. M. A. D. CENTRAL OFFICE
PROCESS CONTROL SYSTEMS

L. P. RODGERS
(313) 492-8215
8-562-8215

GM ASSEMBLY DIVISION
AUTOMATIC VEHICLE IDENTIFICATION
SYSTEM DOCUMENTATION

1

A. V. I. SYSTEM CRITERIA

1. 1 GENERAL SYSTEM REQUIREMENTS

THIS DOCUMENT DESCRIBES THE CRITERIA FOR AN AUTOMATIC VEHICLE IDENTIFICATION (AVI) SYSTEM AS ENVISIONED BY PROCESS CONTROL SYSTEMS OF GENERAL MOTORS ASSEMBLY DIVISION. SYSTEMS WILL BE EVALUATED ON THE BASIS OF HOW THEY MEET THE FOLLOWING CRITERIA.

1. NON-CONTACT
THE IDENTIFICATION DEVICE AND ITS READER SHOULD CONSTITUTE A NON-CONTACT SYSTEM, I. E. THE ID DEVICE SHOULD BE "READ" FROM A DISTANCE. MOST READS WILL BE FROM A DISTANCE OF 1 TO 4 FEET, WITH A MAXIMUM READ DISTANCE OF 10 FEET. IT IS ALSO DESIRABLE THAT THE ID DEVICE CAN BE READ FROM 360 DEGREES. A LINE OF SIGHT SYSTEM IS NOT DESIRABLE DUE TO RESTRICTIONS OF THE ASSEMBLY LINE.

2. PASSIVE
THE ID DEVICE SHOULD BE PASSIVE, I. E. REQUIRE NO POWER OR BE POWERED EXTERNALLY. BATTERY POWERED DEVICES ARE NOT ACCEPTABLE.

3. DURABLE
THE ID DEVICE MUST HAVE THE CAPABILITY TO SURVIVE HOSTILE ASSEMBLY PLANT ENVIRONMENTS. THE VEHICLE, WITH THE ID DEVICE ATTACHED, WILL BE SUBJECTED TO SUCH CONDITIONS AS THE FOLLOWING:

A) TEMPERATURE
THE VEHICLE WILL PASS THROUGH VARIOUS OVENS AT THE COMPLETION OF THE ELECTROCHEMICAL (ELECTROPHORETIC OR ELPO) PROCESS AND DURING THE PAINT PROCESS. VEHICLE EXPOSURE FOR THE ELPO OVEN WILL BE AT A MAXIMUM OF 400 F (200 C) FOR A MAX. OF 60 MINUTES. THE VEHICLE WILL THAN PASS THROUGH A SERIES OF 5-6 PAINT OVENS AT A MAXIMUM OF 400 F (200 C) FOR 30-45 MINUTES EACH. THE VEHICLES ARE ALLOWED TO COOL DOWN BETWEEN EACH OF THE OVENS. (THE DEVICE WILL NOT BE READ WHILE VEHICLE IS IN THE PAINT OR ELPO OVENS).

B) ELECTROSTATIC
THE VEHICLE WILL BE EXPOSED TO AN ELECTROSTATIC PAINT PROCESS WHERE THE VEHICLE IS GROUNDED AND THE PAINT APPLIED FROM A SPRAY GUN WHOSE TIP IS CHARGED AT 125KVDC AT 1 MILIAMP(MAX). (THE DEVICE WILL NOT BE READ WHILE VEHICLE IS IN THE PAINT BOOTH).

C) ELECTROMAGNETIC
WELDING MACHINES UTILIZED IN THE VEHICLE BUILD PROCESS WILL BE THE SOURCE OF ELECTROMAGNEITC INTERFERENCE. MULTIPLE WELDING OPERATIONS OCCURING AT THE SAME TIME MAY GENERATE STRAY CURRENTS AT A POWER LEVEL OF 5 KVA AT 30 VDC. THIS MAY OCCUR FROM WELDING POINTS NOT MAKING REQUIRED CLAMPING AND CONTACT.

D) ELECTROCHEMICAL
THE VEHICLE BODY IS SUBMERGED IN A TANK OF ELECTROPHORETIC PAINT (ELPO). THE VEHICLE IS GROUNDED AND SUBMERGED IN A LIQUID AT 600 VDC. CURRENTS AS HIGH AS 500 AMPS PASS FROM THE LIQUID THROUGH THE BODY TO GROUND. (THE DEVICE WILL NOT BE READ WHILE VEHICLE IS IN THE ELPO TANK).

4. SIZE
THE ID DEVICE MUST BE SMALL. THE IDEAL DEVICE WOULD BE THE SIZE OF A QUARTER, BUT ANYTHING LESS THAN THE SIZE OF A CREDIT CARD WILL MEET OUR DESIRES.

5. COST
THE ID DEVICE SHOULD BE INEXPENSIVE ENOUGH TO BE LEFT ON EACH VEHICLE. RECYCLING OF ID DEVICES IS NOT DESIRABLE DUE TO THE COST OF LABOR, STORAGE, ETC.

6. RELIABILITY
THE AVI SYSTEM SHOULD HAVE A ERROR RATE OF ONE PER MILLION AND A NO READ RATE OF ONE PER TEN-THOUSAND.

7. SAFETY
MICROWAVE AND RADIO FREQUENCY EQUIPMENT MUST MEET OSHA GUIDELINES (EMPLOYEES CANNOT BE EXPOSED TO ELECTROMAGNETIC ENERGY FREQUENCIES BETWEEN 10 MEGAHERTZ(MHZ) AND 100 GIGAHERTZ GREATER THAN 10 MILLIWATTS/CENTIMETER SQUARED (10 MW/CM) AVERAGED OVER ANY 0.1 HOUR PERIOD. IN TERMS OF ELECTRIC FIELD STRENGTH, THE GUIDE IS 200 VOLTS PER METER ROOT MEAN SQUARE.

8. F.C.C. LICENSING
MICROWAVE AND RADIO FREQUENCY EQUIPMENT MUST MEET F.C.C. REQUIREMENTS. HOWEVER, IT IS OUR DESIRE THAT POWER OUTPUT BE RESTRICTED TO LOW ENOUGH LEVELS SO F.C.C. LICENSING IS NOT REQUIRED AT GM ASSEMBLY OR MANUFACTURING PLANTS.

9. PROGRAMMABILITY
THE ID DEVICE SHOULD BE EASILY AND INDIVIDUALLY PROGRAMMABLE IN THE ASSEMBLY PLANT.

10. FLEXIBILITY
THE DECODING EQUIPMENT SHOULD BE EXTREMELY FLEXIBLE TO ALLOW EASY EXCHANGE. MINIMAL TO NO-TUNING SHOULD BE NECESSARY TO REPLACE A UNIT.

11. INFORMATION CAPABILITY
EACH PASSIVE DEVICE SHOULD HAVE THE CAPABILITY TO BE PROGRAMMED WITH 20 ALPHA-NUMERIC CHARACTERS. THIS WILL PROVIDE THE CAPABILITY TO PROGRAM EACH UNIQUE VEHICLE IDENTIFICATION NUMBER (V. I. N.), 17 CHARACTERS, AND ALLOW THE 3 REMAINING CHARACTERS FOR V. I. N. EXPANSION OR SPECIAL FUNCTIONS.

A) ULTIMATELY IT WOULD BE DESIREABLE TO HAVE THE CAPABILITY TO PROGRAM THE ENTIRE VEHICLE MANIFEST IN THE MEMORY OF THE DEVICE. (THE VEHICLE MANIFEST CONSISTS OF APPROX. 300 WORDS OF INFORMATION).

1.2 ENVIRONMENTAL CONDITIONS AND SYSTEM RESTRICTIONS

THE FOLLOWING IS A LIST OF ENVIROMENTAL CONDITIONS AND SYSTEM RESTRICTIONS :

1. THE METHOD OF PROGRAMMING THE TRANSPONDER ON THE FIRST SYSTEM WILL BE A FUNCTION OF PRICE AND INCREASED DURABILITY. IF IT CAN BE SHOWN THAT MAKING THE TRANSPONDER PROGRAMMABLE IN THE PLANT WILL LEAD TO EITHER A SIGNIFICANT INCREASE IN PRICE OR A DECREASE IN SURVIVABILITY, THE ALTERNATIVES SHOULDBE DETAILED.

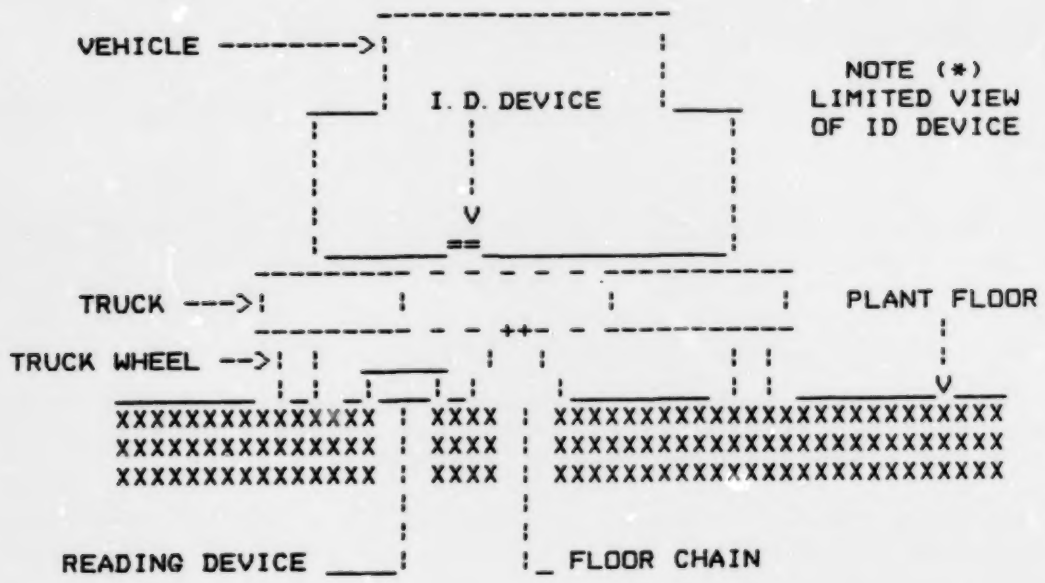
2. THE DATA LENGTH DESIRED FOR FUTURE TRANSPONDER TYPES SHOULD ACCOMMODATE INCREASED LENGTHS. THE EXACT LENGTHS ARE NOT DEFINED , BUT, LENGTHS OF 300 WORDS CAN BE EXPECTED.

3. THE SPEED OF THE VEHICLE WILL NOT EXCEED 25 MILES PER HOUR, WHILE ON THE LINE THE SPEED WILL BE RATED AT 100 JOBS PER HOUR (OR 1/2 FT. /SEC.).

4. THE READING WINDOW FOR A DEVICE ON THE VEHICLE WILL NOT EXCEED ONE FOOT SQUARE. THE AVAILABLE SPACE THROUGH THE VEHICLE CARRIER(TRUCK) WILL BE AS SMALL AS ONE FOOT SQUARE. REFER TO DIAGRAM 1. 7. 1 (TRUCK TYPE) DIAGRAM 1. 7. 2 (POWER AND FREE) AND DIAGRAM 1. 7. 3 (FLAT TOP CONVEYER).

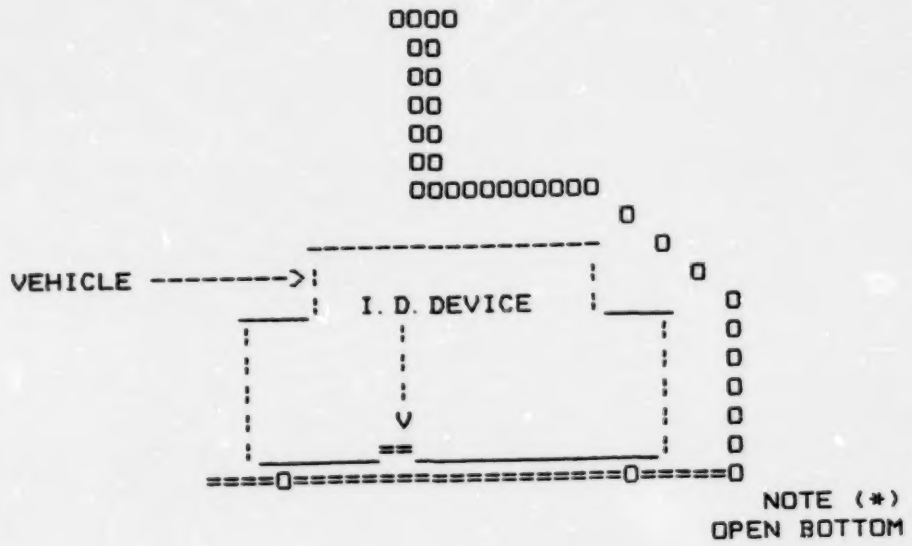
5. THE DISTANCE BETWEEN ANY TRANSPONDER AND THE VEHICLE BODY WILL BE EXTREMELY CLOSE. ALL ATTENUATION FACTORS SHOULD ACCOUNT FOR NO MORE THEN ONE QUARTER INCH.

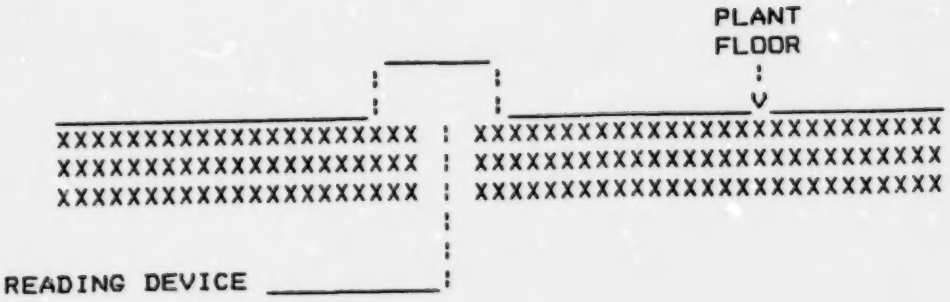
TRUCK TYPE CARRIER



TRUCK TYPE CARRIER DIAGRAM 1.7.1

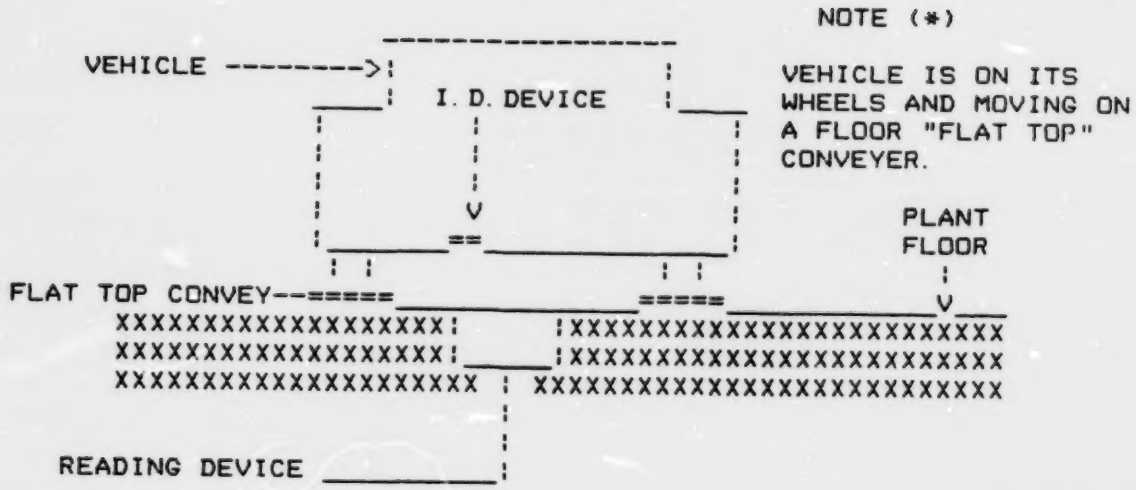
POWER AND FREE CONVEYER





POWER AND FREE CONVEYER DIAGRAM 1.7.2

==========
FLAT TOP CONVEYER
==========



FLAT TOP CARRIER DIAGRAM 1.7.3

APPENDIX B

"SURVEYS OF RADIO COMMUNICATIONS REGULATIONS IN COUNTRIES WHERE ACI MAY BE USED"

GL2400-011
ISSUE 1
22 JUNE, 1982

SURVEY OF RADIO COMMUNICATIONS REGULATIONS IN COUNTRIES WHERE ACI MAY BE USED

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Appendix III - United Kingdom Home Office, (Form BR13). Summary of technical conditions for the licensing of inductive communications and control systems.

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1. INTRODUCTION

The first step in carrying out this work was to determine those countries which should be included in the survey. This was done both on the basis of the marketing activities carried out at the present time by Glenayre Electronics, and also the projected activity which could be foreseen in the immediate future. On this basis the list of countries includes: Canada, the United States, Australia, South Africa, and Great Britain. The second step was to obtain copies of the pertinent radio regulations from each of the aforementioned countries. Upon examination, it was apparent that the regulations could be classified by two distinct and different approaches: the British approach and the United States approach. Under the British classification would be included South Africa and Australia. The Canadian approach appears to fall somewhere between the United States and British classifications.

2. SUMMARY OF REGULATIONS

2.1 The United States Regulations

The United States approach to regulations is to permit the unlicensed operation of radio transmitting devices in certain frequency bands, and for specific purposes. A certification for unlicensed operation will be issued provided the equipment is designed to operate within the published limits of transmitter field strength, frequency stability, etc. The published limits are specified to a level of detail sufficient for the purposes of the equipment designer. The ability to operate unlicensed is a great convenience to the end user of the equipment and thus improves the marketability of the product.

The United States Regulations are published in the Federal Communications Commission (FCC) Rules and Regulations. The regulations pertaining to low power data communications are contained in Volume II, part 15.

As an example of the information presented in the FCC Rules and Regulations, Appendix I contains a copy of those sections which apply to the Glenayre Model 6110 Transponder, and Model 6215 Interrogator as used on the LIC System. This equipment is in fact certified by the FCC for unlicenced operation.

Appendix II contains a copy of those sections which apply to the RAILOCATOR system. Current and future development of this product by Glenayre is not expected to alter the status of the product relative to the application of those regulations.

2.2 United Kingdom

In contrast to the foregoing, the approach to frequency regulations in the United Kingdom makes no provision for unlicenced operation. Each user of a transmitter or receiver must first obtain a licence from the Home Office, where each application is considered on its merits. General similarities exist in the frequencies used for comparable applications, due to International technical pressures enforcing a measure of conformity in the division and usage of the available radio spectrum.

In the context of the United Kingdom, where users are accustomed to obtaining a licence for every radio frequency usage, products do not suffer any especial disadvantage from the licencing requirement.

The high concentration of users in urban British centres creates a general difficulty in obtaining authorization to use certain frequencies. There is no specific correspondence between the frequency bands allocated for similar applications between North America and the U.K., so that changes in operating frequency can generally be expected in attempting to use a North American device in a UK application. Further, some bands are especially heavily used in the UK and it may be impossible to obtain authority for a desired band. A case in point is the use of 27 MHz for low power data communications, which we are advised would under no circumstances be permitted in Britain, whereas it is permitted in North America. Appendix III contains a summary of technical conditions for the licencing of inductive communications and control systems (Form BR13). Appendix IV contains the regulations for the use of radio frequencies for low-power, non-speech devices and Appendix V contains a letter to Glenayre Electronics from the British Home Office suggesting a means whereby the RAILOCATOR device might be approved for use in Britain with slight modifications.

2.3 Australia

The Australian regulations and the approach to them is similar to that of Britain. It is felt that in the remote parts of Northwestern Australia, and even in the Eastern coal producing areas, no major difficulty will be encountered in obtaining permission to use low power devices in and around industrial sites such as mines and rail yards. Appendix VI contains a telex from the Canadian Consulate in Sidney outlining these facts.

2.4 South Africa

The South African regulations are similar in approach to those of Britain. No direct response has been received from the South African authorities, however we are advised that if a major industrial operator such as the railways or a mining company should wish to use a device which qualifies as a "clean" low power device under FCC Regulations, approval from the South African authorities is highly likely.

2.5 Canada

The Canadian Regulations are expressed in a combined format of the United States and Britain.

All radio equipment manufactured or sold in Canada for use in any application other than for the reception of radio news and entertainment broadcast signals and for limited use by licensed radio amateurs, must be covered by a certificate of either "Type Approval" or "Technical Acceptability" as issued by the Canada Department of Communications (DOC). Such certificates are granted only after performance testing of the equipment has been completed. Tests are largely designed to ensure that the equipment will not interfere with other users of the radio spectrum. In the case of equipment requiring Type Approval, DOC publishes a minimum standard specification for the assistance of equipment designers. Such specifications will also establish the use for which the equipment is approved and the minimum radio frequency performance to be achieved. For all equipment where there is no relevant DOC Specification, then a Technically Acceptable Status must be obtained and DOC has discretionary powers to specify the level of testing to be required. In general, the parameters required to be met by DOC are very similar to the U.S. Federal Communications Commission (FCC) for like classes of equipment and service.

As in the United Kingdom, all users of radio transmitting equipment must be licensed, and licenses will only be issued for the use of DOC Type Approved or Technically Acceptable equipment. An exception is made for specific equipment categories as detailed by Section 6 of the General Radio Regulations. At the time when these regulations were being prepared, the concepts of "RAILOCATOR" and Railcar identification equipment were not envisaged, and there is no provision for this category of equipment under the Regulations.

Canada cont'd

In summary, therefore, it would appear that equipment meeting U.S. FCC requirements for unlicensed operation would most likely receive a "Technically Acceptable" certification from DOC. Such a certificate would fulfill the manufacturer's obligation and allow the equipment to be sold for use in Canada. The user of the equipment would still be obligated to obtain an operating license for the equipment from the Canada Department of Communications. Alternatively application would have to be made to DOC so that a specific new category under Section 6 of the General Radio Regulations could be created to exempt the requirement for user licenses.

3. CONCLUSIONS

All initial design work shall be with the objective of producing equipment that will satisfy the requirements of the U.S. Federal Communications Commission (F.C.C.). Specifications for unlicensed operation of low power data communications devices. Approval of the equipment for use in territories controlled by other national radio regulatory bodies will then be obtained on a case by case basis as the requirement arises.

APPENDIX I

UNITED STATES REGULATIONS APPLICABLE TO THE GLENAYRE MODEL 6110 TRANSPONDER AND MODEL 6215 INTERROGATOR

U.S. Federal Communications Commission, Rules and Regulations
Volume II. July 1981.

1. Part 2 Subpart J - Equipment Authorization Procedures, General Provisions.

   1.1 Section 2.901(a) Basis and Purpose

   In order to carry out its responsibilities under the Communications Act and the various treaties and international regulations, and in order to promote efficient use of the radio spectrum, the Commission has developed technical standards for radio frequency equipment and parts or components thereof. The technical standards applicable to individual types of equipment are found in that part of the rules governing the service wherein the equipment is to be operated. In addition to the technical standards provided, the rules governing the service may require that such equipment be verified by the manufacturer or importer, or that such equipment receive equipment authorization from the Commission by one of the following procedures: type approval, type acceptance, certification, or telephone equipment registration.

   1.2 Section 2.907(a) Certification

   Certification is an equipment authorization issued by the Commission for equipment designed to be operated without individual license under Parts 15 and 18 of its rules, based on representations and test data submitted by the applicant.

2. Part 15 Subpart A - General

   2.1 Section 15.1 Scope of this part

   (a) An incidental and restricted radiation device may be operated under the restrictions and provisions set forth in this part without an individual license. The operation of an incidental or restricted radiation device not in accordance with the provisions herein is prohibited by section 301 of the Communications Act of 1934, as amended.

   Note The provisions of an authorized radio service may permit the use of an incidental or restricted radiation device but only in accordance with an individual license and the restrictions set forth in the rules of such authorized radio service.

2.1 Section 15.1 Scope of this part cont'd

(b) The requirements, technical specifications, and equipment authorization procedures for an incidental and restricted radiation device, which apply to the marketing of such a device, are set forth herein. The manufacture and marketing of such a device without prior Commission authorization is prohibited by section 302 of the Communications Act of 1934, as amended.

2.2 Section 15.4 General definitions, sub-section(f) low power communications device.

A low power communication device is a restricted radiation device, exclusive of those employing conducted or guided radio frequency techniques, used for the transmission of signs, signals (including control signals). Writing, images and sounds or intelligence of any nature by radiation of electromagnetic energy.

EXAMPLES: Wireless microphone, phonograph oscillator, radio controlled garage door opener and radio controlled models.

3. Part 15 Subpart D - Low Power Communication Devices: General Requirements.

3.1 Section 15.111 Operations below 1600kHz.

A low power communication device may be operated on any frequency between 10 and 490 kHz or between 510 and 1600 kHz subject to the condition that the emission of RF energy on the fundamental frequency or any harmonic or other spurious frequency does not exceed the field strength in the following table.

Frequency (kilohertz)	Distance (meters)	Field strength (microvolts per meter)
10 to 490.....	300	$\frac{2,400}{F(kHz)}$

3.2 Section 15.116 Operation of a non-voice device between 26.99-27.26 MHz.

A low power communication device may be operated in the band 26.99-27.26 MHz provided it meets all of the following requirements:

(a) The device may not be used for voice communications (F3 or A3), or for CW communications (A1).

(b) The device shall operate on one or more of the following frequencies:

26.995 MHz	27.145 MHz
27.045 MHz	27.195 MHz
27.095 MHz	27.255 MHz

(c) Frequency tolerance of carrier: ±0.01%. This tolerance shall be maintained for a temperature variation of -20° to +50° C at normal supply voltage, and for a variation in the primary supply voltage from 85% to 115% of the rated supply voltage at a temperature of 20° C.

(d) Emission shall be confined within a 20 kHz band centered on the carrier frequency.

(e) The emission of RF energy on the carrier frequency shall not exceed 10,000 uV/m measured at 3 meters.

(f) The out-of-band emissions, including harmonics, on any frequency more than 10 kHz removed from the carrier shall not exceed 500 uV/m measured at 3 meters. The spectrum shall be scanned from 10 to 1000 MHz and all signals exceeding 50 uV/m at 3 meters shall be reported.

(g) If the device is designed to operate from public utility lines, the RF energy fed back into the power lines shall not exceed 100 microvolts on any frequency below 25 MHz.

APPENDIX II

UNITED STATES REGULATIONS APPLICABLE TO THE GLENAYRE "RAILOCATOR" SYSTEM

U.S. Federal Communications Commission, Rules and Regulations Volume II. July 1981.

1. Part 2 Subpart J - Equipment Authorization Procedures, General Provisions

   1.1 Section 2.90(a) Basis and Purpose

   In order to carry out its responsibilities under the Communications Act and the various treaties and international regulations, and in order to promote efficient use of the radio spectrum, the Commission has developed technical standards for radio frequency equipment and parts or components thereof. The technical standards applicable to individual types of equipment are found in that part of the rules governing the service wherein the equipment is to be operated. In addition to the technical standards provided, the rules governing the service may require that such equipment be verified by the manufacturer or importer, or that such equipment receive equipment authorization from the Commission by one of the following procedures: type approval, type acceptance, certification, or telephone equipment registration.

   1.2 Section 2.907(a) Certification

   Certification is an equipment authorization issued by the Commission for equipment designed to be operated without individual license under Parts 15 and 18 of its rules, based on representations and test data submitted by the applicant.

2. Part 15 Subpart A - General

   2.1 Section 15.1 Scope of this part

   (a) An incidental and restricted radiation device may be operated under the restrictions and provisions set forth in this part without an individual license. The operation of an incidental or restricted radiation device not in accordance with the provisions herein is prohibited by section 301 of the Communications Act of 1934, as amended.

   Note The provisions of an authorized radio service may permit the use of an incidental or restricted radiation device but only in accordance with an individual license and the restrictions set forth in the rules of such authorized radio service.

2.1 Section 15.1 Scope of this part cont'd

(b) The requirements, technical specifications, and equipment authorization procedures for an incidental and restricted radiation device, which apply to the marketing of such a device, are set forth herein. The manufacture and marketing of such a device without prior Commission authorization is prohibited by section 302 of the Communications Act of 1934, as amended.

2.2 Section 15.4 General definitions, sub-section(f) low power communications device.

A low power communication device is a restricted radiation device, exclusive of those employing conducted or guided radio frequency techniques, used for the transmission of signs, signals (including control signals). Writing, images and sounds or intelligence of any nature by radiation of electromagnetic energy.

EXAMPLES: Wireless microphone, phonograph oscillator, radio controlled garage door opener and radio controlled models.

2.3 Section 15.4 General definitions, sub-section (j) Field disturbance sensor.

A restricted radiation device which establishes a radio frequency field in its vicinity and detects changes in that field resulting from movement of persons or objects within the radio frequency field.

3. Part 15 Subpart D-Low power Communication Devices: General Requirements.

3.1 Section 15.111 Operations below 1600kHz.

A low power communication device may be operated on any frequency between 10 and 490 kHz or between 510 and 1600 kHz subject to the condition that the emission of RF energy on the fundamental frequency or any harmonic or other spurious frequency does not exceed the field strength in the following table.

Frequency (kilohertz)	Distance (meters)	Field strength (microvolts per meter)
10 to 490.....	300	$\frac{2,400}{F(kHz)}$

4. Part 15 Subpart F - Field Disturbance Sensors

4.1 Section 15.301 Scope of this subpart.

This subpart provides rules governing the operation of restricted radiation devices which are used as field disturbance sensors. Typical examples of devices regulated by these rules are microwave intrusion sensors and devices that use RF energy for production line counting and sensing.

4.2 Section 15.305 General Technical Specification

(a) A field disturbance sensor may be operated on any frequency (including frequencies above 900 MHz) subject to the requirement that the field strength of emissions on the fundamental or on a harmonic or on other spurious frequencies shall not exceed 15 uV/m at a distance of $\lambda/2\pi$ from the sensor.

(b) Alternative to paragraph (a) of this section, a field disturbance sensor may be operated on any frequency listed below, subject to the technical requirements set out in 15.307 and 15.309 of this part.

915 MHz	10,525 MHz
2450 MHz	24,125 MHz
5800 MHz	

4.3 Section 15.307 Permitted Under of operation.

The carrier frequency of a field disturbance sensor operating on one of the frequencies listed in 15.305(b) and any modulation components thereof shall be kept within the following limits:

Nominal operating frequency (MHz)	Band Limits (MHz)
915	±13
2450	±15
5800	±15
10,525	±25
24,125	±50

NOTE: To minimize the possibility of out-of-band 'operation because of frequency drift due to aging of components or other causes, it is recommended that the carrier frequency be kept within the central 80 percent of the permitted tolerance limits.

4.4 Section 15.309 Emmission Limitations

(a) For a field disturbance sensor operating on any frequency listed in 15.307, the field strength of emissions on the fundamental shall be limited in accordance with the following:

Frequency (MHz)	Field Strength
915) 2450) 5800)	50,000 uV/m at 30 meters
10,525)) 24,125)	250,000 uV/m at 30 meters

(b) Harmonic emissions from sensors operating in the bands centered on 915, 2,450 and 5,800 MHz shall not exceed a level of 160 microvolts per meter at 30 meters. Spurious emissions except harmonics shall be suppressed at least 50 dB below the level of the fundamental; however, suppression below 15 microvolts per meter at 30 meters is not required.

(c) Harmonic emissions from sensors operating in bands centered on 10,525 and 24,125 MHz shall not exceed a level of 2,500 microvolts per meter at 30 meters. Spurious emissions except harmonics shall be suppressed at least 50 dB below the level of the fundamental; however, suppression below 15 microvolts per meter at 30 meters is not required.

NOTE: For pulsed operation, measured field strength shall be determined from the averaged absolute voltage during a 0.1 second interval when field strength is at its maximum value. Below 1000 MHz, the measurement bandwidth shall comply with the requirements set out in the American National Standards Institute Specifications C63-2-1963 and C63.3-1964. Above 1000 MHz the measurement bandwidth shall be 5 MHz.

4.5 Section 15.317(g) Frequency ranges over which measurements are required.

For a field disturbance sensor operating above 100 MHz the spectrum shall be scanned from the lowest frequency generated in the device up to 10 GHz, provided that for sensors operating on frequencies above 5 GHz, the spectrum shall be scanned to the highest frequency feasible above 10 GHz. Field strengths of all significant emissions shall be measured and reported.

APPENDIX III

FORM BR 13

Technical conditions for the licensing of Induction Communication and Control Systems operating at frequencies above 16 kHz

1.	TYPE APPROVAL	Full technical details of each type of equipment shall be submitted to the Home Office, Waterloo Bridge House, Waterloo Road, LONDON SE1 8UA who will decide whether it will be necessary to conduct full tests of a specimen before granting approval to the use of the equipment. No technical changes shall be made to approved equipment without the prior consent of the Home Office. Equipment shall be clearly marked with the Maker's name and type number.
2.	FREQUENCIES AVAILABLE	A frequency (or frequencies) specified by the Home Office (normally at the development stage) shall be used in the band 16-150 kHz.
3.	FREQUENCY CONTROL AND STABILITY	The carrier frequency or any reference frequency of the equipment shall not depart from the authorized frequency by more than 0.1 per cent.
4.	TYPES OF MODULATION	Systems using speech or audio-frequency tones to amplitude modulate, or frequency modulate, a radio frequency carrier will be authorized.
5.	BANDWIDTH	The bandwidth shall be the minimum required to ensure the transmission of information at the rate and quality required for the system employed. Sideband emissions at levels down to 6 dB below carrier or reference frequency level shall be such that they do not extend outside the frequency band in 2 above.
6.	DEPTH OF MODULATION	When amplitude modulation is used the depth of modulation shall not exceed 100 per cent.
7.	FIELD STRENGTH	The maximum permitted field strength at 100 yards outside the loop in any horizontal direction shall be 100 microvolts per metre.

8.	ACCESSIBILITY OF CONTROLS	Controls which may affect the technical characteristics of the equipment shall not be accessible from the exterior of the equipment.
9.	SPURIOUS EMISSIONS HARMONIC:S, ETC.	Radiation on any frequency removed from the authorized frequency by more than the authorized bandwidth shall be attenuated below the fundamental frequency by at least 30 dB.
10.	INTERFERENCE	No protection can be given from interference radiated by industrial, scientific or medical equipment or by authorized radio services. Furthermore, in the event of an induction communication or control system causing harmful interference to an authorized radio service or line communication system, the system causing the interference may be required to cease transmission until measures have been taken to prevent a recurrence.

End of Technical Conditions.

APPENDIX IV

FORM BR13

Radio frequencies for low-power non-speech devices

As there are only a limited number of frequencies available for these types of service the use of radio can only be agreed where alternative methods of communication (eg lines, ultrasonics or light beams) cannot reasonably be employed. Applicants may be asked to investigate the possibility of using alternative methods. Each application will be considered on its merits.

Under the Wireless Telegraphy Act 1949 all users of radio require a licence issued by the Secretary of State for the Home Department. development of radio apparatus must be authorized by a Testing and Development License. Such a license must be applied for even if work is to be carried out under suppressed radiation conditions (that is to say in such a way that no electro magnetic energy capable of detection outside the premises where the work is being carried out shall avoidably be emitted). Once equipment has been developed it must be submitted to the Home Office for type approval tests to be carried out. A License for the use of such a system will only be issued where type approved equipment is to be used.

1. General Purpose Telemetry and Telecontrol

   a) 0-150 kHz. This band can be used for induction communication systems operating over a short range. This includes such systems as garage door openers and industrial control equipment. The technical conditions for systems operating in this band are set out in forms BR13 and BR19, obtainable from the Home Office, Radio Regulatory Division.

   b) 173.2-173.35 MHz. Equipment in this band must conform to specification MPT 1309 for low power portable equipment in the VHF band. This specification is obtainable from the Stationery Office quoting SO code No. ISBN 0113406541. Radiated power is normally restricted to 1 milliwatt, but a power of up to 10 milliwatts may be permitted in some cases, at industrial sites.

   c) 458.5-458.8 MHz. Equipment used in this band must also conform to specification MPT 1309 for low power portable equipment in the UHF band SO code No. ISBN 0113406541. The maximum effective radiated power permitted is 1/2 watt.

As regards wide band telemetry requirements consideration will be given to equipment operating in the VHF band only, providing it meets the requirements laid down in performance specification MPT 1309. Wideband Telemetry is not available at UHF.

2. Medical and Biological Telemetry

There are two specifications for medical and biological telemetry equipment covering three separate classes of device.

a) Class 1. This relates to very low power devices, operating between 300 kHz and 30 MHz normally wholly contained within the body of an animal or man (eg radio pills). The normal transmitting range should not appreciably exceed five feet. The specification for this class of equipment is W6802 and copies may only be obtained from the Home Office Radio Regulatory Division.

b) Class II equipment must operate in the band 104.6 - 105 MHz and may consist of wideband equipment covering the whole of the band. The maximum effective radiated power permitted is 1mW.

c) Class III equipment must also operate in the band 104.6 - 105 MHz and consist of narrowband equipment operating on one channel separated by 25 kHz within the band. The maximum effective radiated power permitted is 10 mW.

The performance specification for Class II and III devices is MPT 1312 which may be obtained from the Stationery Office quoting SO Code No. ISBN 0 113406509.

3. Doppler and Sensing Devices

There are five bands available for these devices. Applications for individually installed alarms can be considered, but radio would not be authorized to extend an intruder alarm to other premises, nor to connect several alarms to an agency or central and separate monitoring organization, unless lines were not available.

a) 1489.5 MHz $\pm$ 2.5 MHz. The following conditions apply:

i.	maximum transmitter power:	10 milliwatts peak.
ii.	class of emission:	subject to application.
iii.	aerial gain:	subject to application.
iv.	out of band radiation	any frequency component outside the stated band shall at all times be at least 40dB below the level at carrier frequency.
v.	temperature range:	-5° to +40°C, over which range the stated requirements are to be met.

vi. usage out of doors is not permitted

b) 2450 MHz + 5 MHz. The following conditions apply:

i. maximum transmitter power:	3 milliwatts peak.
ii. class of emission:	subject to application.
iii. aerial gain:	15dB maximum (relative to an isotropic radiator).
iv. out of band radiation:	any frequency component outside the stated band shall at all times be at least 40dB below the level at carrier frequency.
v. temperature range:	-5° to +40° over which range the stated requirements are to be met.

c) 10.587 GHz ± 10 MHz for outdoor use. The following conditions apply:

i. maximum transmitter power:	10 milliwatts peak.
ii. class of emission:	normally A0, P0, F9.
iii. aerial gain:	subject to application but normally not exceeding 20dB (relative to isotropic radiator).
iv. out of band radiation:	any frequency component outside the stated band shall at all times be at least 40dB below the level at carrier frequency.
v. temperature range	-5° to 40°C over which range the stated requirements are to be met.

vi. indoor usage will be permitted only in exceptional circumstances.

d) 10.687 GHz ± 12 MHz. The following conditions apply:

As for 10.587 GHz ± 10 MHz, but for indoor use only.

e) 13.4 - 14.0 GHz. The following conditions apply:

i. maximum transmitter power:	5 milliwatts peak for unmodulated and frequency modulated devices. Consideration will be given for up to 25 milliwatts peak for pulse modulated devices.
ii. class of emission:	normally AO, PO, F9.
iii. aerial gain:	20 dB maximum (relative to an isotropic radiator).
iv. band width of emission:	subject to application.
v. out of band radiation:	any frequency component outside the band width authorized shall at all times be at least 40dB below the level at carrier frequency.
vi. temperature range:	-5° to + 40°C over which range the stated requirements are to be met.

4. <u>The band 27.12 MHz + 0.6%</u>

Requests are frequently received for the use of this band for low power telemetry and telecontrol devices on the grounds that model control equipment which is allowed to operate in the band is readily available. The band, however, is also extensively used by radio paging systems and other services including certain type of medical equipment and congestion is such that use of the band for other categories of service apart from those allowed for under the standard Model Control License (ie strictly for the control of the movement, specifically, of a model vehicle, vessel, or aircraft) cannot be authorized.

NOTE: The information in this leaflet is subject to alteration from time to time. Specific enquiries and request for application forms should be addressed to:

Home Office
Radio Regulatory Division
Waterloo Bridge House
Waterloo Road
London SE1 8UA

ME

HOME OFFICE
Waterloo Bridge House Waterloo Road London SE1 8UA
Direct line 01-275 3119
Switchboard 01-275 3000

Your reference

Mr. G.P. Millett,
Glenayre Electronics Ltd.,
1551 Columbia Street,
NORTH VANCOUVER,
B.C. V7J 1A3,
CANADA.

Our reference
RD/EU/3188
Date
17 February, 1982.

Dear Mr. Millett,

Further to your letter dated 9 December, 1981 concerning the GL 6000 DIGITRAC, the GL 6050 RAILOCATOR and the MIDISS proximity beacon, I regret that none of the frequencies mentioned in your letter would be available for operational use in the United Kingdom.

It is feasible that frequencies covered by the enclosed specification leaflet BR13 could be used in place of 153.6 kHz, 200 kHz and 470 kHz, but there would have to be a considerable reduction in the power of the transmitters to meet the requirements of BR13.

We would consider the possibility of using the 894.5 MHz, ±1 MHz band in place of the requested frequency of 915 MHz for the specific purpose outlined in your letter. The characteristics for equipment operating in the 894.5 MHz band are as follows:-

1. Maximum Radiated Power : 0.5 Watts
2. Tolerance : ±15 kHz
3. All emissions must be contained in the band 894.5 MHz ±1 MHz.
4. Spurious and harmonic radiation must be 40 dB below the mean carrier power or 25 microwatts, whichever is the greatest.

As the frequency 894.5 MHz is currently allocated for anti-theft devices, we would have to impose restrictions on the use of the equipment outlined in your request.

The frequency bands available in the United Kingdom for general purpose low power non-speech devices are outlined in our leaflet BR14, a copy of which is enclosed (as requested in your telex dated 22 January, 1982).

Yours sincerely,

A. KILMINSTER

FEB 2

Encl.

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GLENAYRE VCR

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---PRODUCT TYPE APPROVAL
INFORMATION YOU PROVIDED IN YR DEC31 CORRESPONDENCE HAS BEEN FORWARDED TO THE RADIO FREQUENCY MANAGEMENT DIV OF DOC. ONCE DOC HAVE PROVIDED APPROPRIATE FEEDBACK WE WILL, IN TURN, ADVISE YOU. FOR YR GENERAL BACKGROUND INFO, APPEARS AUSTLN PROCEDURES MORE IN LINE WITH THAT OF UK SINCE VIRTUALLY ALL DEVICES REQUIRE LICENSING. NORMALLY, PRODUCTS ARE SUBMITTED TO DOC FOR TYPE TESTING AND ONCE OVERALL APPROVAL IS RCVD THEN INDIVIDUAL END-USERS APPLY FOR PERMISSION TO OPERATE.

CANADIAN CONSULATE SYDNEY, AUSTRALIA

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GLENAYRE VCR
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APPENDIX C

AUTOMATIC CAR IDENTIFICATION SPECIFICATION

GL 4001
Issue I
15 March 1982

AUTOMATIC CAR IDENTIFICATION

SPECIFICATION

Prepared by:

G.P. Millett

Approved by:

R.J. Faberoy

DISTRIBUTION LIST

Glenayre Electronics Ltd.	W. Tracey
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Transport Canada Transport Development Centre:	N.E. Rudback (Scientific Authority) - 2 Copies
Science Procurement Branch, Department of Supply & Services:	D.W. Reinboldt (Science Procurement Manager)

DOCUMENT CHANGE RECORD

Date: 15 March 1982
Issue: I, Original
Changes: None

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1. SCOPE

1.1 This document specifies the design objectives for an electronic system for the automatic identification of rail cars.

1.2 The specification is written to a level of detail sufficient to define the target requirements for the system. No limitations are imposed on the designer as to how these minimum requirements are to be met.

2. APPLICABLE DOCUMENTS

2.1 "Further development of Railocator," GL2400-009 Issue 2.

2.2 "Automatic Car Identification (ACI)," System Specification for American Railroads, January 31, 1977, and Change Notice No. 1 February 28, 1977.

2.3 "Functional Requirements and Operations Specifications for a System for the Automatic Identification of Railway Rolling Stock," South African Railways, undated.

2.4 "Specification for Weighbridge Vehicle Identification," TMC 1842, Australian Iron & Steel Pty., Ltd., Port Kembla, Australia, undated.

The above applicable documents have been used as a reference source for the preparation of this specification. This specification is the entire specification and shall take precedence over all other documents. Any further implementation of specifications that may be derived from the above documents shall be at the discretion of the designer.

3. REQUIREMENTS

3.1 General Requirements

3.1.1 The Automatic Car Identification (ACI) System will consist of the following items:

3.1.1.1 A Transponder (electronic car label), that may be attached to any item of railroad rolling stock, and which shall contain permanently recorded identification data.

General Requirements cont'd.:

3.1.1.2 An Interrogator (label detector) that will read the electronically recorded identification data contained in the Transponder.

3.1.1.3 A Car Detector that will detect the presence of all items of rolling stock whether or not equipped with Transponders.

3.1.1.4 A Controller that will receive identification data from Interrogators and car detection data from the Car Detectors. The Controller validates, time tags and stores incoming data, and transmits this data to a "HOST" computer upon demand, via a suitable communications network. The Controller shall provide the power for the Interrogator and as far as is practical for the Car Detector.

3.1.1.5 A Field Programmer that can be used by Transponder installation crews to encode and verify the identification data in the Transponder.

3.1.2 The "HOST" computer and the communications network referenced in paragraph 3.1.1.4 are to be supplied by others, and are not a part of this specification. However, the Controller will provide the necessary interface to transfer data to and from the communications network, as required by the "HOST" computer.

3.2 The Transponder

3.2.1 The Transponder shall be a self-contained single unit package that can be quickly and easily fixed to the bottom of any type of railroad rolling stock including steam, diesel and electric locomotives, cabooses, freight and passenger cars.

3.2.2 The Transponder shall be packaged so that it may be mounted easily without interfering with existing vehicle safety appliances and appurtenances, and be installed by railroad mechanical personnel.

3.2.3 The Transponder shall not require a power source from the vehicle on which it is mounted.

The Transponder cont'd:

3.2.4 The Transponder may be a sealed non-repairable unit.

3.2.5 The car identification data to be recorded and permanently retained within the Transponder shall, at a minimum, consist of a ten decimal digit number. Design consideration is to be given to expansion to allow the encoding of four alpha characters followed by seven decimal digits. If the Car Detector used to detect the presence of rail cars is to utilize axle or wheel sensing techniques, then the last decimal digit shall be used to indicate the number of axles on the item of rolling stock to which the Transponder is fitted.

3.2.6 It should be possible to encode the car identification number into the Transponder in the field at the time of Transponder installation.

3.2.7 The allowable distance between successive Transponders in a train shall be not more than five times the distance between the Interrogator and the Transponder.

3.2.8 The Transponder shall be designed for a service life of twenty (20) years, and to be maintenance free save for visual inspections.

3.2.9 The Transponder shall be designed to operate under the following environmental conditions:

3.2.9.1 The Transponder shall continue operating at ambient air temperatures between -25 degrees C., to + 70 degrees C, without consideration of the effects of exposure to direct sunlight.

3.2.9.2 Design consideration will be given to developing a Transponder with an extended operating temperature range to -55 degrees C., and which could be offered as an option to selected customers.

3.2.9.3 The Transponder shall continue to operate with an encrustation of railroad oil, dust and grease typical of the under car railroad environment.

3.2.9.4 The packaging of the Transponder and its mounting will recognize the corrosive nature of many rail car cargos and the inevitability that there will be some spillage of lading. Suitable measures must be provided to shield Transponders so that they are not damaged, or their operation impaired by such minor spills.

3.2.9.5 Transponder operation must not be affected by the nature of the associated rail car cargo. (Metals, metallic ores etc.)

3.2.9.6 Transponders shall be designed to withstand and continue operating under the extremes of humidity vibration, shock, and altitude encountered by externally mounted equipment on railroad rolling stock. This shall take into account exposure to salt fog, direct solar radiation, snow, ice and white frost build-up.

3.2.9.7 Transponders shall suffer no long term damage due to intermittent immersion in salt water.

3.2.9.8 Transponders shall be unaffected by direct lightning strikes to rolling stock.

3.2.10 Design effort shall be directed towards ensuring that the cost of manufacture of the Transponder is held to an absolute minimum.

3.3 The Interrogator

3.3.1 The Interrogator shall be packaged so that it may be mounted between the rails of a metre gauge track with due allowance being made for rail fasteners. The interrogator shall not project above the height of the rails.

3.3.2 The Interrogator shall read Transponders that are mounted on surfaces that are nominally parallel to the Interrogator mounting plane and with a separation of between 300 mm to 1150 mm between mounting planes.

3.3.3 The Interrogator shall read Transponders when the range is varying cyclically ±80 mm at approximately 5 c.p.s. due to vehicle spring bounce.

3.3.4 The Interrogator shall read Transponders that are tilted ±15 degrees in any direction or combination of directions relative to the Interrogator mounting plane.

3.3.5 The Interrogator shall read Transponders that are misaligned up to ±15 degrees relative to the direction of travel.

3.3.6 The Interrogator shall read Transponders that are displaced ±360 mm relative to the centre line of the Interrogator at the minimum range. This displacement includes the sum of installation misalignments, car sway, and tracking errors due to changes in car/track geometry on curves.

3.3.7 The Interrogator shall read Transponders that pass either forwards or backwards at any speed from 0 to 200 km/h.

3.3.8 Design consideration shall be given to the development of a track side Interrogator capable of reading Transponders over a range of 2.75 metres.

3.3.9 It shall be possible to operate several Interrogators simultaneously with a radial separation between Interrogators of 20 meters.

3.3.10 Interrogators shall be capable of operating with 35 metres of interconnecting cable between the Interrogator and the Controller.

3.3.11 The Interrogator shall be designed to operate under the following environmental conditions:

3.3.11.1 The Interrogator shall operate at ambient air temperatures between -25 degrees C., and +70 degrees C, without the consideration of the effects of exposure to direct sunlight.

3.3.11.2 Design consideration will be given to developing an Interrogator with an extended operating temperature range to -55 degrees C., and which could be offered as an option to selected customers. The use of electrically powered heaters is an acceptable solution to this problem.

3.3.11.3 The Interrogator shall continue to operate with an encrustation of oil, grease and dust build-up on exposed surfaces as is normal for equipment mounted between the rails.

3.3.11.4 The Interrogator shall be impervious to damage due to strikes and abrasion from track ballast.

3.3.11.5 The Interrogator shall withstand and continue operating under the extremes of humidity, vibration, shock, and altitude encountered by externally mounted track equipment. This shall take into account exposure to salt fog, direct solar radiation, snow, ice and white frost build-up.

3.3.11.6 The Interrogator shall suffer no long term damage due to intermittent immersion in salt water.

3.3.11.7 The Interrogator shall withstand severe lightning activity to the exclusion only of direct strikes and strikes to the adjacent track or trackside equipment, or failure of external power supplies.

3.3.11.8 The Interrogator operation and installation shall take account of routine track and track bed maintenance procedures using either manual or mechanized processes.

3.4 The Car-Detector

3.4.1 A Car Detector shall be provided which may be a wheel or axle counter, or any other suitable technology.

3.4.2 The Car Detector shall detect the presence of all items of rolling stock.

3.4.3 The Car Detector shall indicate the direction of travel for each item of rolling stock.

3.4.4 The Car Detector shall only provide one indication of the presence of a car or wheel for each pass of that car or wheel through the zone of influence of the detector. Should a car or wheel happen to stop within the zone of influence of the detector, limited forward or backward movements, that do not take the car or wheel outside of the zone of influence, shall not produce a second count.

3.4.5 The Car Detector shall not require the presence of a Transponder or the installation of any other special device on rolling stock in order to perform its detection function.

3.4.6 The Car Detector shall meet the same environmental criteria as specified for the Interrogator. (See paragraph 3.3.12).

3.5 The Controller

3.5.1 The Controller will accept inputs from at least four Interrogators and four Car Detectors.

3.5.2 The Controller will co-ordinate received Interrogator and Car Detector data, so that cars not fitted with a Transponder may be identified.

3.5.3 The Controller will identify one event per car that passes through an Interrogator and its associated Car Detector. Each event will consist of either a Transponder reading or a Car Detector count.

3.5.4 Should a car stop whilst it is in the detection zone of an Interrogator, the Controller will only identify a single event, and will ignore limited forward and backward movements of the car. (The term "limited" requires further definition but suggests as a minimum that this may only apply to movements that do not take the car outside of the detection zone of the Interrogator/Car Detector).

3.5.5 The Controller shall tag each train with date and time. To this end the Controller will contain a Real-Time clock that will provide day, month, year and twenty four hour notation time in hours, minutes.

3.5.6 The Real-Time clock shall be resettable by the HOST computer.

3.5.7 The Real-Time clock shall be provided with an optional "no-break" back-up battery power supply sufficient for twelve hours of clock operation. The back-up supply will incorporate an automatic charger to provide quick recharging, maintenance trickle charging, and protection of the battery against excessive discharge if necessary, to prevent damage to the battery.

3.5.8 The Controller will check the validity of all received data, and indicate any detected error by the inclusion of an appropriate character in the event data.

3.5.9 The controller shall have a memory with capacity to store event data from a minimum of 500 cars, for each Interrogator/Car Detector pair connected to the Controller.

3.5.10 The Controller shall transmit its stored event data to a "HOST" computer, upon receipt of a polling signal. Transmitted data will be erased from memory upon receipt of an acknowledge signal from the HOST computer. In the event of no acknowledgement being received, data will continue to be stored and be retransmitted on next and subsequent polling cycles. Suitable measures will be taken to protect collected data should the data in storage approach the maximum memory capacity of the Controller.

3.5.11 The Controller will transmit a two part message to the HOST computer upon receiving a polling signal. One part will be the "regular" data message, whilst the other will provide an indication to the HOST computer of equipment status, either normal or malfunctioning and covering all significant aspects of the Interrogator, Car Detector, Controller System.

3.5.12 The "regular" data message from the Controller will contain the following information:

3.5.12.1 Controller Identification No. (01-99).
3.5.12.2 Date (82:03:01).
3.5.12.3 Message Daily Sequence No. (001-999).
3.5.12.4 Interrogator/Car Detector Identification No. (0-9).
3.5.12.5 Time of first and last item of rolling stock (13:10).
3.5.12.6 Direction of car travel. (One alpha character as defined by the HOST computer).
3.5.12.7 Transponder data.
3.5.12.8 A message word if received transponder data did not pass validity checks.
3.5.12.9 If no Transponder is fitted to an item of rolling stock then a Car Detector message or an axle count will be substituted for the Transponder data.

3.5.13 The reliability of the message from the Controller shall be a minimum of 1 in 100,000 vehicle readings for undetected errors, and 1 in 10,000 for detected errors.

3.5.14 In no case shall it be acceptable to miss an entire piece of rolling stock, or to generate a signal indicating the presence of an extra piece of rolling stock.

3.5.15 The Controller will interface with a communications network to be supplied by others. The interface output shall be serial, CCITT V24 compatible, with a bit-oriented protocol. Line speeds of 1200, 2400, 4800 and 9600 bits/second must be supported. The required character codes are ASCII or EBCDIC.

3.5.16 The Controller shall operate from single phase AC railroad power, either 100, 110, 115, 120, 125 and 127V ±15% or 200, 220, 230, 240V ±15% at 47-63 Hz.

3.5.17 The Controller shall be provided with an optional "no-break" back-up battery power supply, sufficient to supply power for all system requirements for a minimum of six minutes. The back-up battery will be provided with an automatic charger to provide quick recharging, maintenance trickle charging, and protection of the battery against excessive discharging if necessary to prevent damage to the battery.

3.5.18 The Controller shall have a programmable 300-1200 Baud Serial ASCII port for maintenance purposes.

3.5.19 The controller shall be designed to operate under the following environmental conditions.

3.5.19.1 To be mounted in a suitable track side environmental enclosure which may be electrically heated. The environmental enclosure is not a part of this specification.

3.5.19.2 The Controller shall operate at ambient air temperatures between -25 degrees C., and +70 degrees C.

3.5.19.3 The Controller shall be protected against power surges and transients on incoming communications and power lines due to lightning activity. Severe lightning activity other than direct strikes and external power failures shall not affect Controller operation.

3.5.19.4 The Controller shall withstand and continue

operating under the extremes of humidity, vibration, shock, and altitude that may be encountered by pole mounted track side environmentally protected equipment. Environmental protection enclosures may be heated for extreme cold weather operation but will not be cooled in hot weather. The Controller shall operate without the use of cooling fans.

3.6 The Field Programmer

3.6.1 The Field Programmer shall be designed for operation by railroad mechanical repair crews.

3.6.2 The Field Programmer shall provide all necessary means for encoding the Transponders with the necessary identification data, prior to Transponder installation.

3.6.3 The Field Programmer will have facilities for displaying the digits and characters to be encoded into the Transponder, so that the setting of the Field Programmer can be readily verified by untrained personnel prior to encoding the Transponder.

3.6.4 The Field Programmer will have facilities for reading the coded Transponder and displaying the digits and characters so read in a form that can be readily verified by untrained personnel.

3.6.5 The Field Programmer shall operate from single phase AC railroad power, either 100, 110, 115, 120 and 127V $\pm$15% or 200, 220, 230 240V $\pm$15% at 47-63 Hz.

3.7 System Requirements

3.7.1 The correct functioning of the system must not be affected by strong magnetic fields produced by permanent or electro-magnets, traction motors and generators using AC or DC voltages to 50 KV, or power transmission lines, catenaries and similar conductors, carrying 5,000 Amps at 500 KVolts.

3.7.2 The equipment must not be affected by, nor may it interfere with, signalling or communication lines, or radio frequency communications or detection systems of any type including airport equipment and VHF or UHF portable radio equipment used by train staff.

3.7.3 All equipment with the exception of the Field Programmer shall be designed for unattended operation.

3.7.4 With the exception of the Transponder, the system shall be designed to require routine maintenance at a minimum interval of 90 days.

3.7.5 The system shall meet the requirement of the U.S. Federal Communications Commission (FCC) and the Canada Department of Communications (DOC) for operation on an unrestricted basis including the vicinity of airports etc.

3.7.6 The design of the system shall strive for a maximum Mean Time Before Failure (MTBF) consistent with the use of readily available commercial components and good design practice, and avoiding the necessity for redundancy.

3.7.7 The Mean Time to Repair (MTTR), including fault isolation to the replaceable module level, module replacement, and verification of operability shall not exceed one hour. This takes into account the average skill level of railway communications and or signalling electronic technician personnel who have had a training course not to exceed one week. The MTTR does not include travel time to and from the site.

APPENDIX D

GL2400-013
ISSUE 2
15 FEB, 1983

AUTOMATIC CAR IDENTIFICATION

(ACI)

CONTROLLER SOFTWARE SPECIFICATION

Prepared By: C.E. Elder

Approved By: P. Boetzkes

DOCUMENT CHANGE RECORD

DATE: 15 February 1983

ISSUE: 2

CHANGES: Major changes throughout document

DISTRIBUTION LIST

Glenayre:

B. Searle
P. Boetzkes
C. Elder
D. Caesar

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APPENDICES

Appendix A - Table of Valid Transponder Codes

1. SCOPE

1.1 This document specifies the design objectives of the software for the Controller module of the Automatic Car Identification (ACI) system to a level of detail required for its implementation.

2. APPLICABLE DOCUMENTS

2.1 'Automatic Car Identification Specification', GL4001, Issue 1.

2.2 'ACI Host/Controller Communications Protocol', for South Africa Railway, GL2400-014, Issue 1.

This document should be used in conjunction with those above. If any discrepancies arise regarding the Controller software, this document will take precedence.

3. GENERAL REQUIREMENTS

3.1 The Controller software should be as simple and reliable as possible.

3.2 The software will be written in Z80 assembly language using Ithaca's ASMBL/Z mnemonics. Thus it will be compatible with both the Zilog Z80 and the National Semiconductor NSC800 microprocessors.

4. SOFTWARE SPECIFICATION

4.1 Data Input

4.1.1 The Controller will be capable of handling input from up to four Interrogators and four pairs of Axle Detectors. One pair of Axle Detectors will be associated with each Interrogator.

4.1.2 Interrogator information will be BCH-encoded. BCH checking and stripping will be done in the Controller hardware, and only BCH error-free information will be reported to the processor.

Interrogator reports will consist of 35 information bits, divided into five 7-bit codes, representing the received transponder information.

4.1.3 The Axle Detectors will be monitored at 2 msec intervals, with the assumption that an axle situated between a pair of Axle Detectors will be detected by at least one of the pair.

Axle Detector reports will consist of a flag indicating whether an axle is currently in the detection zone.

4.2 Data Handling

4.2.1 The Controller will provide additional error-checking on Interrogator reports, i.e. it will check that all received transponder codes fit in our 100 in 128 protocol (see Appendix A). Data that fails this check will be tagged as invalid.

4.2.2 Transponder data will be decoded into five 2-decimal-digit bytes. The Controller currently assumes that the number of axles on a car will be equal to the last (tenth) digit.

4.2.3 The Controller will determine whether a new axle has been detected, based on whether there has been a change in the associated Axle Detector report since the last poll.

4.2.4 The Controller will co-ordinate received Interrogator and Axle Detector data, so that cars not fitted with a Transponder will be detected and identified as unlabelled cars with an associated number of axles. (Note that several consecutive unlabelled cars will necessarily appear to the controller as one long car).

4.2.4.1 The Controller will subtract the axles associated with labelled cars from the total axle count between transponders. A remainder greater than zero will represent an unlabelled car with that number of axles.

4.2.4.2 Normally, the Controller will not pool a transponder number as soon as it is received. If the number repeats once, it will be considered confirmed and will then be pooled. All further repetitions will be ignored. If no repetitions occur before another axle is detected, the number will be pooled at that time.

4.2.4.3 If more than one transponder number is read between two axles:

- If no valid number is repeated, only the last valid numer will be pooled. (If none is valid, the first number will be pooled).
- If one valid number is repeated, it will be the only number pooled.
- If more than one valid number is repeated, the axle detectors will be considered to have failed, and all subsequent transponder numbers will be pooled.

4.2.5 The Controller will recognize and ignore extra transponder readings from trains that are 'shunting' (moving back and forth) in the detection zone.

4.3 Real-Time Clock

4.3.1 The Controller will have a software Real-Time Clock that provides the year, month, day, hours (00-23), minutes, and seconds.

4.4 Data Storage

4.4.1 The Controller will avoid restart-loaded RAM data, using ROM whenever possible.

4.4.2 The Controller will have a unique ID that will be hardware-encoded and monitored as required for Host communications.

4.4.3 The Controller will store all collected data in an event pool with up to 2000 entries, or an average of 500 entries per interrogator. Each entry will be stamped with the associated interrogator (channel) number. The following types of events will be pooled:

- A train entry into the detection zone, including the direction and BCD date and time of entry.

- A combined axle count and following transponder number (decoded to BCD), including a transponder validity flag and the direction of the axles.

- An axle count including the direction of the axles.

- A train exit from the detection zone, including the direction and BCD time of exit.

4.4.4 Suitable measures will be taken to protect the most significant collected data should the data in storage approach the maximum memory capacity of the Controller. The oldest transponder information will be overwritten first, with axle counts being preserved as long as possible. When only train entry and exit information remains, it will be overwritten event by event beginning with the oldest event. The only exception to this is that the last received event on any channel will always be preserved.

4.4.5 The Controller will store status information that will indicate detected equipment failures in any aspect of the Interrogator, Axle Detector, and Controller system. This will include:

- Interrogator Failure (*4)
- Axle Detector Failure (*4)
- Loss of Prime Power
- Loss of Battery Backup Power
- Memory Storage Overflow
- Controller Software Failure

4.5 Host Interface

4.5.1 Communications with the Host processor will follow the protocol specified by the document of section 2.2.

4.5.2 For immediate test purposes, a simple asynchronous protocol to an ASCII terminal will be used. Upon receipt of a polling character from the Host terminal, the Controller will transmit the following:

- the Controller status information of section 4.4.5
- the real time and date
- every pooled event that has not yet been transmitted (in chronological order)
- an update of the Controller status
- the real time and date

4.5.3 The Host terminal will also be able to set the Real-Time Clock.

4.6 Diagnostic Features

An RS-232 port will be available for diagnostics. All event data that is pooled will be output via this port in ASCII characters. Upon receipt of a polling signal, the Controller status of section 4.4.5 and the real time and date will also be output. It will be possible to set the Real-Time Clock via this port.

APPENDIX A

Valid 7-bit Transponder Codes (100/128)

	0100010		1100010
	0100011		1100011
	0100100	1000100	1100100
	0100101	1000101	1100101
	0100110	1000110	1100110
	0100111	1000111	1100111
0001001	0101001	1001001	1101001
0001010	0101010	1001010	1101010
0001011	0101011	1001011	1101011
0001100	0101100	1001100	1101100
0001101	0101101	1001101	1101101
0001110	0101110	1001110	1101110
0001111	0101111	1001111	1101111
0010001	0110001	1010001	1110001
0010010	0110010	1010010	1110010
0010011	0110011	1010011	1110011
0010100	0110100	1010100	1110100
0010101	0110101	1010101	1110101
0010110	0110110	1010110	1110110
0010111	0110111	1010111	1110111
0011001	0111001	1011001	1111001
0011010	0111010	1011010	1111010
0011011	0111011	1011011	1111011
0011100	0111100	1011100	1111100
0011101	0111101	1011101	1111101
0011110	0111110	1011110	1111110
0011111	0111111	1011111	1111111

APPENDIX E

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